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RESULTS OF BENCHMARKING ERGONOMICS EVALUATION OF EXPLOSIVE ORDNANCE DISPOSAL (EOD) PERSONAL PROTECTIVE EQUIPMENT (PPE) STANDARD PROGRAM

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July 2005 – January 2006

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U.S. Army Research, Development and Engineering Command
Natick Soldier Center
Natick, Massachusetts 01760-5020

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No current standard exists for any aspect of Explosive Ordnance Disposal suit performance. The National Institute of Standards and Technology Office of Law Enforcement Standards asked the US Army Natick Soldier Center (NSC) to develop a Standard for future EOD suits. As part of the development of the EOD Personal Protective Equipment (EOD PPE) Standard, NSC's Ergonomics Team evaluated several ergonomics aspects of current commercial EOD suits. The tested suits are the latest available to agencies for purchase. The suits were tested to determine their baseline or current performance level. This performance level will be used to develop minimum acceptable performance levels and representative test methodologies for future EOD suit development. This report details the ergonomics tasks and tests and their results used in developing benchmarks.

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Preface

As part of the development of the EOD Personal Protective Equipment (EOD PPE) Standard, current commercial EOD suits were evaluated. The tested suits are the latest available to agencies for purchase. The suits were tested to determine their baseline or current performance level. This performance level will be used to develop minimum acceptable performance levels and representative test methodologies for future EOD suit development. This report details the ergonomics tasks and tests and their results used in developing benchmarks. The work was funded by Department of Homeland Security, National Institute of Standards and Technology (NIST) under Interagency Agreement M42356. The work detailed in this report was completed from July 2005 to January 2006. The Appendices for this report contain data recorded during the benchmarking evaluation and are published separately as NATICK/TR-06/015L.

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RESULTS OF BENCHMARKING ERGONOMICS EVALUATION OF EXPLOSIVE ORDNANCE DISPOSAL (EOD) PERSONAL PROTECTIVE EQUIPMENT (PPE) STANDARD PROGRAM

1. Background and Purpose.

a. No current standard exists for any aspect of Explosive Ordnance Disposal (EOD) suit performance. The National Institute of Standards and Technology Office of Law Enforcement Standards has asked Natick Soldier Center to develop a standard for future EOD suits. As part of the development of the EOD Personal Protective Equipment (EOD PPE) Standard, the Ergonomics Team evaluated several ergonomics aspects of current commercial EOD suits. The tested suits are the latest available to agencies for purchase. The suits were tested to determine their baseline or current performance level. This performance level will be used to develop minimum acceptable performance levels and representative test methodologies for future EOD suit development. This report details the ergonomics tasks and tests and their results used in developing benchmarks.

b. In order to successfully render explosive devices safe, the EOD technician must be able to accomplish several tasks efficiently and safely. These may include:

- Walking up to several hundred meters during the approach from a safe area (and return to the safe area as many times as called for by the situation),
- Climbing over barriers and negotiating obstacles (such as doorways, stairs, guardrails, curbing, etc.) and negotiating varied terrain, both indoors and outdoors,
- Carrying necessary tools and equipment,
- Set-up of equipment at the scene, including x-ray apparatus and disrupter,
- Accessing small or difficult-to-reach areas such as those found under or inside vehicles
- Manipulation of various tools/items such as ropes, pulleys, clips, carabiners, and shock tubes.

The suit must also allow the user to see well enough to complete these tasks and to do so with as little fatigue from weight, bulk, and heat retention as possible. Successful EOD operations will be compromised if these tasks cannot be fully accomplished.

The tasks above are not all-inclusive, but are representative of the tasks a technician would be expected to accomplish.

In order to develop a performance standard for ergonomic characteristics of bomb suits, these tasks must be taken into account. The standard for ergonomic performance, therefore, is based on the benchmark performance of current state-of-the-art suits in tests that examine part or all of each of those tasks. The benchmark objectives are described below.

2. Approach.

The benchmarking process included tests based on technical performance aspects of the suits (most based on prior EOD suit testing as in reference 1.) and on tests developed from EOD scenarios presented in the User Guide (the User Guide aids agencies in testing candidate items prior to purchase, and the scenarios in that guide are based on feedback received from EOD personnel. See reference 2.)

The tests used are fully described in the Methods section which follows, but generally, the tasks included donning and doffing time, some preliminary "pass/fail" tasks, operation of switches and controls, gross dexterity, gross body mobility, two test scenarios that replicate tasks EOD personnel need to complete while wearing an EOD suit, and a questionnaire dealing with the acceptability of various suit characteristics.

3. Methods.

a. Subjects. Eight subjects participated in this evaluation. All were drawn from Natick's Human Research Volunteer Company. All eight test participants were males; no women were available in the group who could be accommodated by the suit sizes available for testing. A broad range of body sizes was requested (within the sizing constraints of the available suits and sizes), in order that testing included a large size range of subjects who could wear each of the available suits. None of the eight were EOD technicians. All were in good physical condition. None had vision or hearing problems. Subject age and time in service is presented in Table 1. Subject body dimensions and suit sizes are found in Table 2.

Table 1. Subject Age and Time in Service.

	Mean	SD
Age (years)	22.1	3.4
Time in service (months)	9.0	4.5

Table 2. Subject Body Dimensions.

Subject Number	Weight (lbs)	Height (in)	Chest Circ. (in)	Waist Circ. (in)	Hip Circ. (in)	Suit Size		
						Mark V	Med-Eng	Safeco
1	167	70.6	39.6	32.9	36.9	3	Medium	Medium
2	200	72.2	42.4	36.1	41.1	4	Medium	Medium
3	164	69.4	38.3	34.1	37.3	3	Medium	Medium
4	162	69.1	37.7	33.5	36.5	3	Medium	Medium
5	187	68.5	41.9	36.0	39.8	3	Medium	Medium
6	185	72.6	41.3	35.8	39.4	4	Medium	Large
7	195	73.0	39.4	34.6	41.7	4	Medium	Large
8	190	72.5	39.7	33.9	39.8	4	Medium	Large

b. EOD Suits.

The EOD PPE team purchased the current state-of-the-art EOD suits, which were used in several tests, including ergonomics testing. The suits are the following:

(1) British Military (Allen-Vanguard) Mark V suit (Mk V). This suit has been approved for issue to members of the United Kingdom Military's EOD squads and has recently become available for purchase by other agencies (sold by Allen-Vanguard outside the UK). Unlike many EOD suits, the Mk V is a seven-piece suit. It includes inner and outer jacket and trouser parts, a groin and buttocks protective set of "shorts," an articulated rigid thoracic plate system, and helmet. The helmet is a one-size-fits-all (adjusted to head size by removable pads) open-face helmet with a flip-up faceshield. The faceshield includes a heated layer to help minimize interior surface fogging. A power supply attached to the rear of the helmet powers the heated layer in the faceshield. An air blower provides adjustable ventilation to both the front inside of helmet (by a hose routed near the neck) and to a ventilating vest to cool the back thorax. A shoulder-mounted switch controls the ventilation speed. A separate power supply, mounted in a jacket pocket, powers the ventilation system. An impact protective back protector was not available in the tested suit. The Mk V is available in five sizes, based on several body dimensions. The EOD PPE team purchased one suit in size 3, and was loaned a size 5 system by Allen-Vanguard for ergonomics testing.

(2) Med-Eng EOD-8. This suit is currently sold by Med-Eng Systems, a Canadian company, and is the most commonly used system by both civilian and military

bomb disposal units. It is a four piece system that includes a jacket with built-in plates; trousers, with built-in articulated impact protective back protector; a groin and buttocks protective set of "shorts"; and helmet. The full face helmet shell is available in one size with a separate removable faceshield. The helmet includes a ventilation system, as well as an electronics package that conveys ambient sounds to built-in earphones. A jacket-mounted power supply powers the ventilation and audio system. A replaceable anti-fog appliqué is included with the faceshield and was used for this benchmarking. The EOD-8 suit is available in four sizes that are based upon height and weight. The EOD-8 was available for testing in all four sizes.

(3) Med-Eng EOD-9. This suit is the latest design by Med-Eng. It was introduced in the fall of 2004, with production capacity and sales beginning in early 2005. It is a four-piece system similar in design to the EOD-8. The system includes a jacket with built in plates; trousers, with built in articulated impact protective back protector; a groin and buttocks protective set of "shorts"; and helmet. The helmet is a one-size-fits-all (adjusted to head size by removable pads) open face helmet with flip up faceshield. The helmet includes a ventilation system that is integral to the helmet, as well as an electronics package that conveys ambient sounds to built-in earphones. The faceshield includes two built in LED lamps to provide auxiliary lighting, if needed. A replaceable anti-fog appliqué (installed inside the helmet for this benchmarking) and a replaceable heated appliqué can be applied to the inside of the faceshield. The system includes an electronics control pad that is mounted on the wearer's wrist. The control pad allows the user to control or activate helmet ventilation speed, helmet speaker volume, heated faceshield, and handsfree lighting. The helmet has its own power supply mounted to the rear of the helmet. A separate power supply with greater power capacity is mounted in a jacket pocket. Either power supply may be used during equipment usage, but the larger jacket-mounted power supply was used during this benchmarking. The EOD-9 suit is available in four sizes that are based upon height and weight. The EOD PPE team had two EOD-9 suits available, in sizes Medium and Large.

(4) Safeco 2010. This suit is the current suit sold by the Safeco division of Protective Materials, Inc. It is a three piece system that is composed of trousers, a jacket, and helmet. The helmet is full face with a separate removable faceshield and a ventilation system. The ventilation system is powered by a jacket pocket- mounted power supply using a Makita 9.6 volt battery. The helmet is available in two sizes: Medium and Large. The chest and abdomen plates are removable from the jacket. An articulated impact protective back protector is built into the rear of the jacket. Four extremity armor upgrade panels can be inserted into the trouser legs to increase protection[1]. This suit is available in two sizes based on waist and chest circumference. The EOD PPE team purchased three Safeco suits (two Medium and one Large).

[1] The extremity armor panels were installed in the Safeco suit for the entire test.

These four suits are the latest versions available to the EOD user community, both civilian and military. The Mk V suit is substantially different in its design approach as compared to the other suits. The Mk V suit, like the others, is the result of many years of iterative design; it was included here so that different suit styles and designs would be represented in the benchmarking process.

c. Conducted Tests. Descriptions of the tests are as follows:

(1a) Donning and doffing time. Time to don and doff the suits in a non-emergency situation.

(1b) Visor Fogging Evaluation (Pass/Fail).

Note that this test is conducted separately from the remainder of the ergonomics tests described in this report due to availability and access to temperature-controlled chambers, and the results are not reported here.

(2) Preliminary Evaluation Tasks (Pass/Fail Gate).

- String a recovery line through a pulley and attach a carabiner. Rate as GO/NO GO.
- Wearer should be able to stand up without help after laying flat on the ground on his back. Rate as GO/NO GO.
- Wearer will visually locate and recover a coin placed approximately 12 inches behind him by turning in place and looking down, but cannot take more than one step in any direction. This demonstrates working in confined spaces and is a check of forward and downward vision. Rate as GO/NO GO.

(3) Test of operation of all functions, switches, and controls on the suit and the helmet (including quick-release operation). The user should be able to reach and use all of the items without assistance, especially the quick-release. A GO/NO GO is recorded for this test.

Any suit that fails *any* of these preliminary tests or the operation tests (tests (2) and (3)) would not be considered further; all suits that pass moved on to the remaining tests. The remaining tests involve performance-based criteria, creating objective, repeatable data for scoring tested EOD suits.

The performance-based test items included the following:

(4) Gross dexterity (hand manipulation). The Minnesota Manual Dexterity Test is a test of gross finger and whole-hand dexterity. A subject picks up and turns over a series of wooden disks with the lead hand, and replaces them with

the following hand. The score is the time to complete the board containing 60 disks. The board was placed on the ground lengthwise and the test subject approached the board, positioned himself near the board to comfortably manipulate the disks, and executed the task.

(5) Field of view testing. Because the jackets and helmets prevent use of a perimeter (a visual testing device commonly used for determining field of view), a method used in prior EOD suit testing was used. This method involved using a laser pointer to project a point on each of eight arcs marked on a blank wall, with the subject seated the appropriate distance from the wall. The point is moved out of the subject's field of view, and then back into view. The subject signals when he loses sight of the point, and then signals again when the point again becomes visible. This method replicated the process and visual angles used by a perimeter.

The center of the eight arcs was 50 1/8 inches above the floor, and the subjects sat in a height-adjustable chair to complete the field of view test. The chair was positioned so that its center (and the subject's eyes) was 36 inches from the center of the arcs.

(6) Gross body mobility. Most of these tests are conducted using a goniometer, which measures the angular displacement of a body joint (e.g., elbow, shoulder, knee) in order to quantify the range of motion. (Details on executing these tests are presented in reference 1.; they require knowledge of the anthropometry of the human body in order to properly execute them). Tasks to test mobility included:

- Walk Forward: Five Steps. The subject takes five steps forward, each as far forward as possible. The distance from the heel of the foot when starting to the toe of the foot taking the fifth step is measured and recorded.

- Walk Backward: Five Steps. The subject takes five steps backward, each as far backward as possible. The distance from the heel of the foot when starting to the toe of the foot taking the fifth step is measured and recorded.

- Side Step: Five Steps. The subject steps sideways as far as possible each time until five steps are taken. The distance traveled is measured from the outside of the foot when starting to the outside of the foot completing the fifth step.

- Upper Arm Abduction. A subject is asked to raise his arms sideward and upward as far as possible. A goniometer measures the amount of abduction.

- Upper Arm Forward Extension. The subject raises his arms as far forward and upward as possible. A goniometer measures the degree of extension.

- Upper Arm Backward Extension. With the palm facing away from the body, a subject is asked to raise the arm as far backwards and upwards as possible. The measurement is the angle of backward extension, recorded from a goniometer. The subject stands at a corner to prevent bending at the waist, which will artificially increase the angle.

- Upper Leg Abduction. A subject raises his leg as far sideward and up as possible while avoiding leg rotation and bending of the knee. The subject holds onto a support (e.g., the back of a chair) while performing this movement. The angle of abduction is measured by a goniometer.

- Upper Leg Forward Extension. Holding the back of a chair for support, the subject raises the leg as far forward and up as possible. A goniometer measures the amount of extension.

- Upper Leg Backward Extension. Standing against a wall for support, the subject moves the leg as far backward and upward as possible. The angle of movement is measured with a goniometer.

- Upper Leg Flexion. Allowing the knee to bend freely, the subject raises his upper leg as far up as possible. The subject grasps a support (the back of a chair) while raising his leg. The amount of flexion is measured with a goniometer.

- Kneel and Rise. A subject is rated as to his ability to rise from a kneeling position, either with or without assistance. The subject begins in a standing position, gets down on both knees, and stands up again. The rating scale is: (0=cannot get down on both knees, 1=cannot rise from kneeling position without help from experimenter, 2=can rise from kneeling position but needs to grasp object, 3=can rise from kneeling position without any help at all).

(7) Test course 1 (negotiation to/from device). This course included walking and climbing over obstacles. The test criterion is time to complete the task. It is designed to replicate many of the types of movements an EOD technician would be expected to execute in approaching and leaving the area of a device. The course was laid out as follows, indoors:

Note: The course was 6 feet (1.82 meters) wide except at the stairs, which were 47 inches (1.19 m) wide between the handrails.

- When the subject was given the start signal, the timer was started. The subject proceeded to walk 200 feet (60.96 m) from the start point at a normal pace.
- The subject descended a flight of stairs[2] to the landing.
- The subject climbed up a flight of stairs back to the starting floor.
- The subject proceeded 65 feet (19.81 m), climbed over a w-beam guardrail or equivalent[3], and proceeded 50 feet further.
- The subject stopped and proceeded to walk backwards 50 feet to the guardrail or obstacle, climbed over it backwards, and walked backwards an additional 15 feet. The course and time ended once the subject covered the 15-foot distance behind the guardrail, walking backwards.

A guardrail mockup was used in this test; it was 4 feet long, 3 inches wide/deep, and 27 1/8 inches high[4].

This course did not include 'disruption' procedures. These procedures were separated from test course 1 to facilitate determination of difficulties and so that time to complete the task represents an easily understood variable.

(8) Test course 2 (disruption procedure). This course included processes conducted as the technician is 'on target,' in close proximity to the device. Tasks here tested the suit as the technician attempted to see, locate, and set up a disrupter during a 'disruption' procedure. The idea is to document the "time on target" needed to accomplish disrupter setup. The main body mobility tasks were bending/stooping and locating items under a desk. The tasks for this course were:

- When the subject was given the start signal, the first timer was started. The subject picked up the disrupter and proceeded to walk 50 feet (15.24 m) from the start point at a normal pace. The subject carried a disrupter (with the legs folded in and the barrel folded flush against them) with shock tube (or substitute)[5] attached. One end of the shock tube was already attached to the disrupter; the other end was loaded onto a wooden spool and the tube played out behind the subject as he negotiated the course.
- Subjects walked a distance of 28 feet and then turned left 90 degrees and walked through a doorway to enter the room with the device.

[2] The flight of stairs was comprised of 11 stairs, each 7 ½" high (rise) and 11 ½" deep (run).
[3] The guardrail should be mounted with the top of the rail at the standard height of 27 inches, or use an obstacle 27 inches tall, 3 to 3.5 inches wide/deep and several feet long.
[4] The standard guardrail height according to AASHTO (American Association of State Highway and Transportation Officials) recommendations is no more than 27 inches tall for W-beam type guardrail. Safe design and construction of the mockup required an additional 1/8" of height.
[5] For this evaluation, 0.090" thick string trimmer line was used in place of shock tube.

- When the subject reached a point 10 feet (3.05 m) from the device, a second timer was started. This timer recorded the subject's "time on target."
- The subject stopped at a desk. A one-cubic foot box (12"x12"x12") was located under the desk on the floor so that the side nearest the subject was 18 inches behind the front edge of the desk. The bottom edge of the desktop was 28 inches from the floor, and the desk had a chair opening 27 ¾ inches wide.
- The subject put the disrupter down next to him, and got onto his hands and knees. He crawled under the desk and located a mark[6] placed in the center of the side of the box. He then moved the disrupter into position (using marks on the floor as a guide for the placement of the base to achieve a 6 inch standoff from the target to the end of the disrupter barrel), angled the barrel so that it is aimed at the mark on the box, and made sure that the adjustment mechanism was tight. He verified the aim by attaching a laser aiming pointer over the barrel of the disrupter, turned it on, readjusted the barrel as needed, then turned off and removed the pointer.
- The subject then crawled backward out from under the desk, stood up, and grasped the shock tube. He then walked backward, guiding himself backwards by the shock tube. At a point 10 feet from the device, the second timer was stopped. The subject continued to walk backwards another 12 feet until reaching the door, then turned around to walk back normally 28 feet to the starting point
- The first timer was stopped when the subject returned to the starting point.

The disrupter model used in testing was an Ideal PAN Disrupter Unit (Model K100) with aluminum stand, weighing 28 pounds. It was a folding model that did not use a vertical rod for barrel positioning. The weight of the disrupter was recorded, since there are different types available to the EOD technician and so that others using this test procedure can use the same disrupter/weight. An Ideal model K2001 Laser Sight and Adapter were used for aiming of the disrupter.

All of the benchmarking tests were spelled out specifically as to layout, methodology, and execution, so that others can repeat them easily.

(9) Additional Tests. In conjunction with the human factors tasks detailed above, the test suits were evaluated on several additional items. Many of these items were tested independently from the human factors tasks (i.e., during the inspection and familiarization process), but all are benchmarking items that need analysis and reporting. These additional tests included:

[6] The mark was a circle the diameter of a quarter, or 15/16", with a small dot in the center.

- Battery Life. Determine the longevity of one set of batteries. At a minimum, any batteries in a system (to run blowers, visor defoggers, etc.) should last for one test session with a test subject (approximately 2 hours). This information was not calculated specifically, but battery performance was recorded in terms of test session completion.
- Ability to remove and/or change batteries with or without tools.
- Qualitative analysis of suit components to determine if there are any significant problems with the suit due to poor design or manufacturing errors.
- Determine if the User Instructions (owner's manuals) are present, comprehensive, accurate and up to date.
- Determine if the helmet and suit interface properly and prevent unacceptable gaps.
- Determine adequacy of helmet retention system in terms of retention capability and adjustability.

These items (except for battery life) are reported separately by suit in the Appendix.

d. Procedure. Each of the subjects performed each of the tests described in the previous section once for each suit. The tests were conducted in the same order for each subject. In order to facilitate testing, two subjects were tested at the same time. Testing time per condition (suit) was approximately 2 hours, including time for rests/breaks. Testing took place during September 2005.

Subjects were given ample opportunity to take rest breaks and had water available to them at all times. An evaluator always accompanied a subject when test courses were run as a safety check. Subjects were able to 'opt out' of testing at any point without penalty[7]. All testing took place in an air-conditioned lab with the temperature at approximately 66-68° F. The test courses were run indoors.

Suit presentation was randomized; each suit was presented first, second, or third an equal number of times over the group of subjects. This minimized as much as possible any fatigue or practice effects that may have occurred.

Subjects were measured and fitted for the suits in a pre-test session. The subjects tested each suit in the same way, with the tests run in the following order:

- Donning time. Subjects were instructed in how to don the suit prior to beginning a timed trial. An evaluator acted as a "buddy" and assisted with donning in every trial.

[7] None of the subjects opted out of the evaluation.

- Preliminary Evaluation Tasks (Pass/Fail Gate). The subjects were instructed how to perform these three tasks before they performed them. If they did not perform them properly, the trial was re-run (all subjects performed the tasks properly, so none of them were asked to re-do a task).

- Test of operation of all functions, switches, and controls on the suit and the helmet. After these items were demonstrated for the subject, he was asked to reach and use all of them without assistance. Operation of controls was performed once per condition per subject.

Had a suit failed any of the preliminary tasks or operational task items, the subject would not have continued testing that suit.

- Gross dexterity (hand manipulation) test. Each subject performed this test twice in each suit, with a short break in between trials. The subject also had a 10-minute practice session in a pre-test session without an EOD suit; this reduced any improvement in time to complete the task due simply to a practice effect. The subject's score for this test was the arithmetic mean of the two timed trials.

- Field of View testing. Each subject tested each suit's field of view one time.

- Gross body mobility testing. Each of the mobility tasks except for Kneel and Rise was conducted 3 times in immediate succession for each condition, with the test score being the arithmetic mean of the three trials. Kneel and Rise is a 'pass/fail' type of task, and therefore was run only once per suit per subject. The subjects were instructed properly so that the movement was clear, and so that the subject stopped moving the arm or leg at the proper point.

- Test course 1 (negotiation to/from device). The evaluator walked and/or demonstrated the course with the subject prior to the actual timed trial, to familiarize the subject with the course. Marks on the floor indicated the starting, ending, and intermediate points of the course.

- Test course 2 (disruption procedure). The evaluator walked and/or demonstrated the course with the subject prior to the actual timed trial, to familiarize the subject. The subject was also instructed on how to manipulate the disrupter and operate the laser aiming device prior to use. The evaluator attached the shock tube prior to the start of this course; the subject did not do so. Markings were provided at the proper distance and location for disrupter placement to assist in setup and aiming of the disrupter.

- Doffing time. Subjects were instructed in how to doff the suit prior to beginning a timed trial. An evaluator acted as a "buddy" and assisted with doffing in every trial. Quick-release functions were tested during doffing, as applicable.

The test courses were run at the end of the evaluation because the subject was most familiar with the EOD suit by this point in the evaluation. On the test courses, subjects were verbally coached if they forget the next action to take; they were not assisted in any other way during the trial.

At the conclusion of the evaluation session, the subjects completed a questionnaire dealing with the acceptability of various suit and helmet attributes. The subject rated the acceptability of these features based on their experiences with the suit in the test session they had just completed.

In addition, after the final test session, the subjects rank-ordered the four suits in order of preference from best to worst suit; they were asked to provide reasons why the suits were ranked in that order.

4. Results.

In the results that follow, suits are coded A, B, C, and D to prevent direct identification of brand/model. Manufacturers were briefed on the results of the evaluation and were instructed as to which code refers to their suit(s).

General comments about the suits, test process, or a particular sub-test are provided by subtest in the relevant section below; specific suit-related information is presented by subtest in the Appendix.

Statistical testing was performed on the data from each subtest to determine whether there were any significant differences between the suits on a particular subtest. For most subtests, the test was a one-way analysis of variance (ANOVA) with Bonferroni correction applied to post-hoc tests. For the questionnaire data, a Friedman test was performed for each question; a Friedman test is analogous to a one-way ANOVA for non-parametric data.

The results below include the results of the statistical testing, indicating whether a statistically significant difference between suits existed. A significant difference is indicated in the tables as $p<.05$, which means that there is a greater than 95% probability that the difference truly exists and is not just a random occurrence within the data collected.

The results also provide error bar charts, which show the range of the mean between one standard deviation below and one standard deviation above the mean at a 95% confidence interval (indicated in the figures as *"95% CI"*). This indicates that there is a 95% probability that the mean would fall within the limits of the indicated bar.

Both the tested mean data and the error bar charts will be used to set the benchmarks for the standard.

Comments provided by the test participants and observations noted by test personnel were recorded throughout the benchmarking evaluation. The comments are presented separately in the appendix when the item refers only to one suit and may reveal the suit's identity.

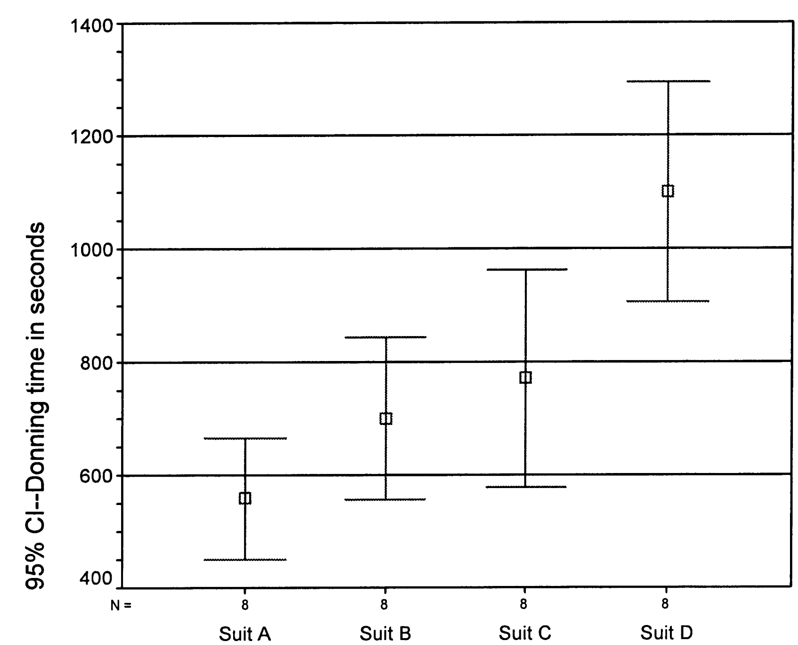
a. Donning and doffing time. This subtest measured the time to don and doff the suits in a non-emergency situation.

Donning times ranged from 9 minutes 18 seconds for suit A to 18 minutes 20 seconds for suit D. Suits A and B were donned significantly faster than suit D. No other significant differences were found. None of the subjects had any great difficulty in donning the suit with assistance. There were some problems or concerns specific to particular suits. See the appendix for these items. Table 3 lists the mean donning times for suits individually, as well as the average time for the group. Figure 1 displays the error bars for donning time.

Table 3. Donning Time.

Donning Time (min:sec)	**Suit A**	**Suit B**	**Suit C**	**Suit D**	**Overall Donning Time**
Mean	9:18	11:41	12:51	18:20	13:02
SD	*2:09*	*2:52*	*3:49*	*3:51*	*4:34*

Suits A and B were donned significantly faster than suit D (p<.05)



Suits A and B were donned significantly faster than Suit D (p<.05). N=number of subjects.

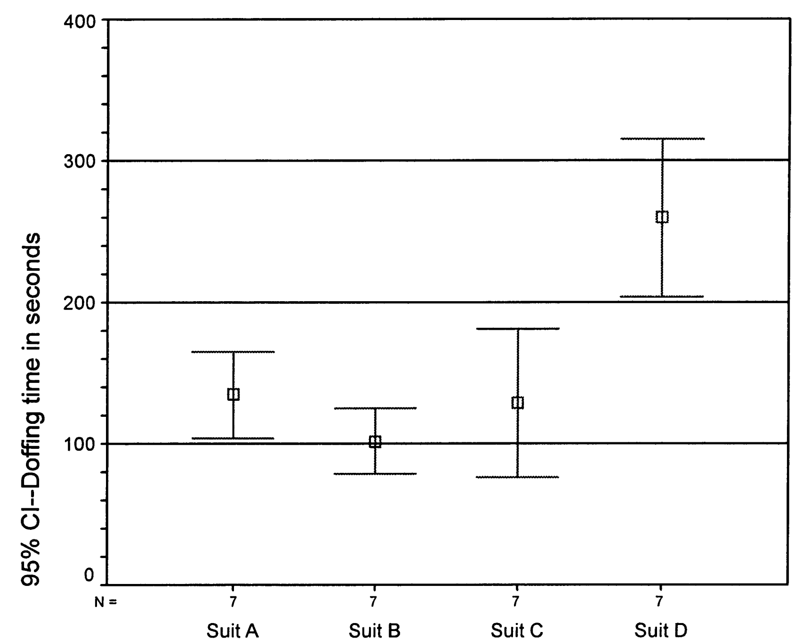
Figure 1. Error Bars for Donning Time.

Doffing times ranged from 1 minute 42 seconds for suit B to 4 minutes 14 seconds for suit D. Subjects doffed Suit D significantly more slowly than any of the other suits. None of the subjects had any great difficulty in doffing any suit with assistance, and the quick-release functions (where present) generally worked as designed. There were some problems or concerns specific to particular suits. Table 4 lists the mean doffing times for suits individually and as a group. Figure 2 displays the error bars for donning time.

Table 4. Doffing Time.

Doffing Time (min:sec)	Suit A	Suit B	Suit C	Suit D	Overall Doffing Time
Mean	2:12	1:42	2:16	4:14	2:38
SD	*0:32*	*0:25*	*0:56*	*0:58*	*1:13*

Suit D was doffed significantly more slowly than any other suit (p<.05)



Suit D was doffed significantly more slowly than the other 3 suits (p<.05). N=number of subjects.

Figure 2. Error Bars for Doffing Time.

b. Preliminary Evaluation Tasks (Pass/Fail Gate).

- *String a recovery line through a pulley and attach a carabiner.* The subjects usually had to hold the line, pulley, and carabiner at a certain distance and location relative to the helmet and faceshield in order to see them properly. However, all of the subjects completed this task in all of the suits.

- *Wearer should be able to stand up without help after laying flat on the ground on his back.* All of the subjects were able to stand back up without help in all of the suits. They usually rolled to the side, then pulled the legs up under the body, knelt, and then stood up.

- *Wearer will visually locate and recover a coin[8] placed approximately 12 inches behind him by turning in place and looking down, but cannot take more than one step in any direction.* Although some of the subjects could not see the coin at various points depending on the suit and helmet, all were able to find and retrieve the coin. Some had to maintain a mental reference of where the coin was last seen, and then feel for the coin. Others could not see the coin when first turning around but were able to see the coin once they bent over. None took more than one step. Details by suit are found in the appendix.

c. Test of operation of all functions, switches, and controls on the suit and the helmet (including quick-release operation). In most cases, the subjects were able to operate all of the switches and controls on each of the suits. In most cases, this involved manipulation of blower speed controls. There were cases where some of the controls were not accessible, but this would likely not affect render-safe procedures.

Suit "quick-release" functionality was tested during doffing, as applicable to the suit. In all cases where present, the subjects could reach and use the quick-release, and it functioned properly with no problems or concerns.

More specific details of a suit's performance on this sub-test are found in the appendix.

d. Gross dexterity--Minnesota Manual Dexterity Test. There were no significant differences between suits in completion time for either trial, and there were no significant differences in the number of errors committed by the subjects for either trial. Completion times for Trial 1 ranged between 2 minutes 17 seconds and 3 minutes 11 seconds. The mean number of errors committed during Trial 1 ranged from 0.75 to 3.1. In Trial 2, completion time ranged from 1:55 to 2:35, and the mean number of errors ranged from 1.0 to 2.5. Table 5 lists the results of the testing, and Figures 3 through 6 display the error bars for completion time and number of errors for both trials.

Errors were defined as disks that were not fully placed into the board, dropped (whether or not it was recovered—i.e., not picked up and placed in the board, often because it rolled out of the subject's reach), or those that were turned over by the subject accidentally (including those knocked out by a part of the suit). Generally, errors resulted from some part of the suit (usually the sleeve or the sleeve cuff) contacting the board and moving disks out of place. Some of the time, the subject would 'bobble' a disk and drop it.

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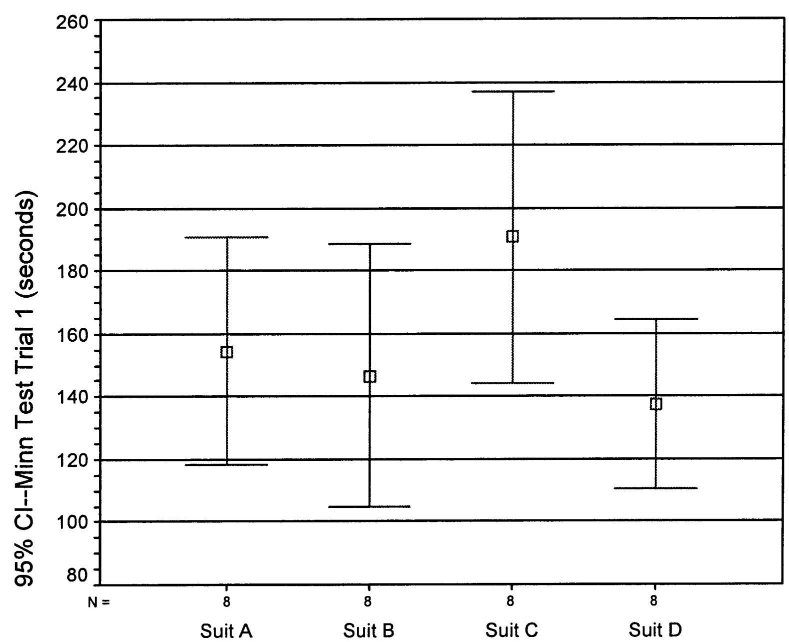
[8] A US 25 cent coin (a "quarter")

Table 5. Minnesota Manual Dexterity Test Results.

	Suit A		Suit B		Suit C		Suit D		Overall	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Trial 1 Mean Time (min:sec)	2:35	*0:44*	2:39	*0:54*	3:11	*0:56*	2:17	*0:32*	2:40	*0:49*
Trial 1 Errors (mean)	0.8	*0.7*	1.5	*1.3*	3.1	*2.7*	1.0	*0.9*	1.6	*1.8*
Trial 2 Mean Time (min:sec)	2:18	*0:41*	2:23	*0:34*	2:35	*0:48*	1:55	*0:24*	2:18	*0:39*
Trial 2 Errors (mean)	1.0	*1.1*	2.1	*1.6*	2.5	*1.9*	2.0	*2.2*	1.9	*1.8*

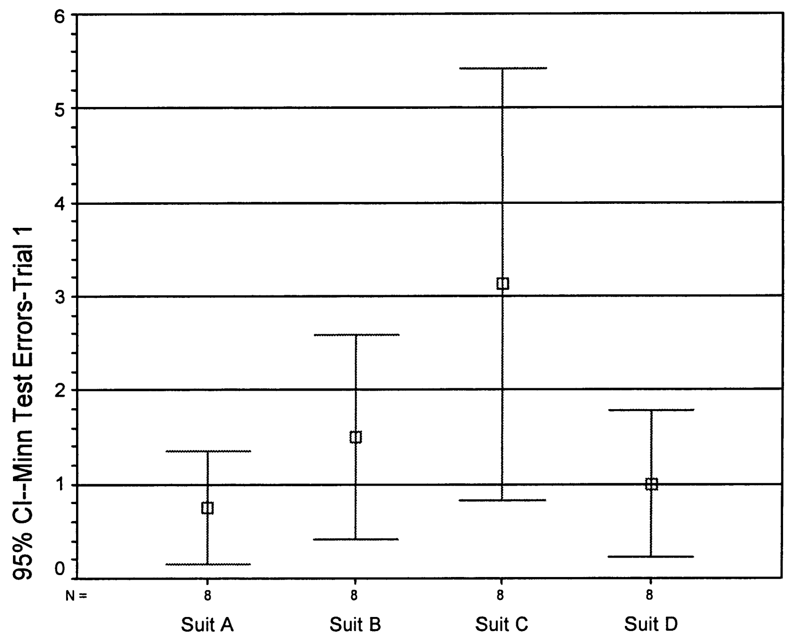
There were no significant differences between suits for time to complete or number of errors.

Subjects were allowed to position themselves any way they chose to complete the test, and to change position as often as they felt it was necessary. Most knelt in front of the board, while others lay in front of the board. A few knelt and leaned on their elbows, using only their forearms to move the disks. Most of those who lay on the floor to begin the trial ended up kneeling in front of the board by the end of the trial. In a few cases, subjects felt fatigued enough on this task that they stopped and rested during the trial for a few seconds before resuming.



None of the suits' scores differed significantly (p<.05). N=number of subjects.

Figure 3. Error Bars for Minnesota Test Trial 1 Time to Complete.

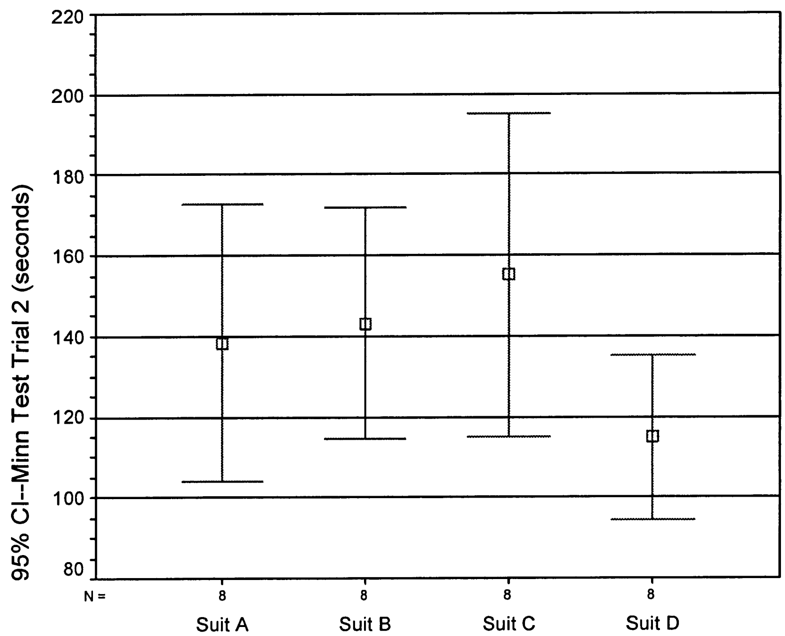


None of the suits' error scores differed significantly (p<.05). N=number of subjects.

Figure 4. Error Bars for Minnesota Test Trial 1 Errors.

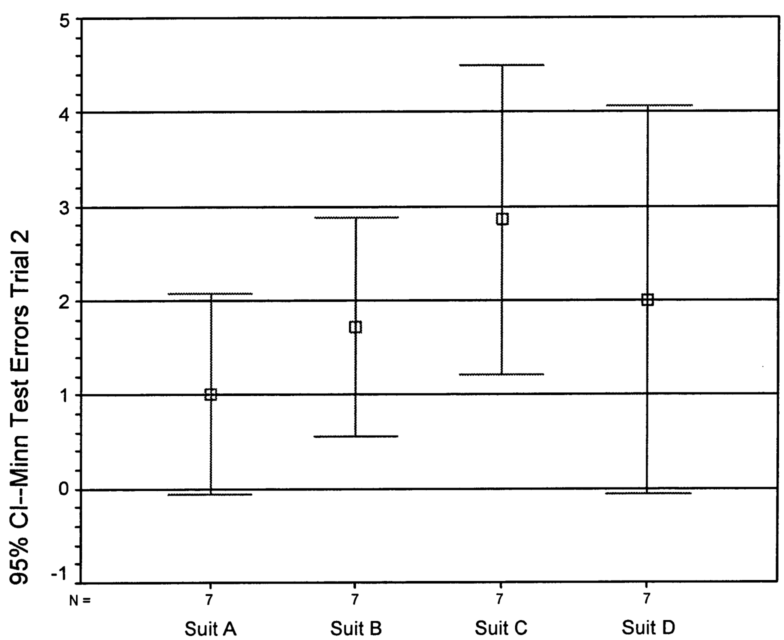
In several cases, the test was made more difficult because of the groin protector and/or the chest plate. Some of the subjects could not position themselves close enough to the board for easy manipulation of the disks. When this occurred, it was caused by groin protector and/or chest plate contact with the floor, preventing the subject from bending as far over as he wished and making access to the board (especially the far side) more difficult.

Details by suit are presented in the Appendix.



None of the suits' scores differed significantly (p<.05). N=number of subjects.

Figure 5. Error Bars for Minnesota Test Trial 2 Time To Complete.



None of the suits' error scores differed significantly (p<.05). N=number of subjects.

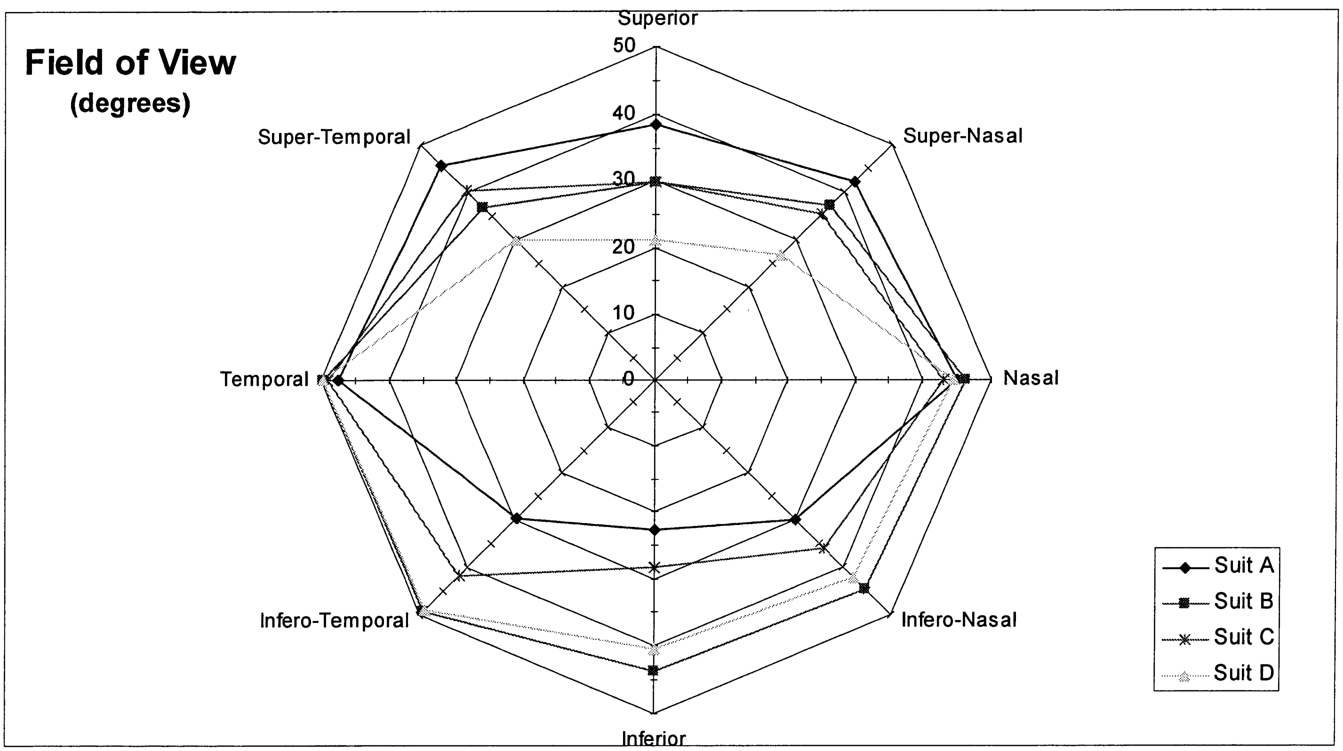
Figure 6. Error Bars for Minnesota Test Trial 2 Errors.

e. Field of view testing. All of the suits offered approximately equal field of view side-to-side (left-to-right) (approximately 42-50°). In the upward direction, Suit D provided the worst upward vision (21.2°) while Suit A offered the best (38.4°), with Suits

B and C tied in between them (29.7°). Downward, visual field was greatest for Suits B and D (43.6° and 40.4° respectively) and the worst for Suit A (22.5°), with Suit C in between (28.1°). On the other axes, visual field generally remained in the same order (greatest to least field of view).

All of the subjects had properly fitting helmets during the field of view testing. In a few trials, fogging occurred during testing. When fogging occurred, testing was stopped, the face shield was removed, and the fogging was allowed to clear before testing resumed. Details are provided in the Appendix.

See Figure 7 for a graphic representation of the field of view results. Note that the graph is collapsed (right eye collapsed into left eye, since field of view is symmetrical)[9] and represents the perspective of the left eye.



Seen from perspective of left eye

Figure 7. Field of View of Tested Suits.

f. Gross body mobility. All but one of the task scores were the measurement of the angle (in degrees) through which the concerned body part (shoulder, knee, elbow, etc.) had passed as measured at a joint. The "Kneel and Rise" task was similar to a GO-NO GO task and, as such, statistical analysis was inappropriate.

[9] Field of view is symmetric assuming subjects have no eye or visual deficiencies that would preclude symmetry. None of the subjects in this evaluation had any deficiencies.

Two of the nine body mobility tasks involving degree scores demonstrated significant differences between suit scores. For Upper Arm Abduction, Suit C had significantly less mobility than Suit B and Suit D. On Upper Arm Forward Extension, Suit C demonstrated significantly less mobility than the other three suits. None of the other tasks revealed significant differences between suits.

Generally, the subjects had little difficulty in performing the body mobility tasks. Subjects demonstrated no major balance problems in performing the "5 steps" tasks. The suits limited the range of motion but did not necessarily make the tasks difficult to execute. Specific details by suit are found in the appendix.

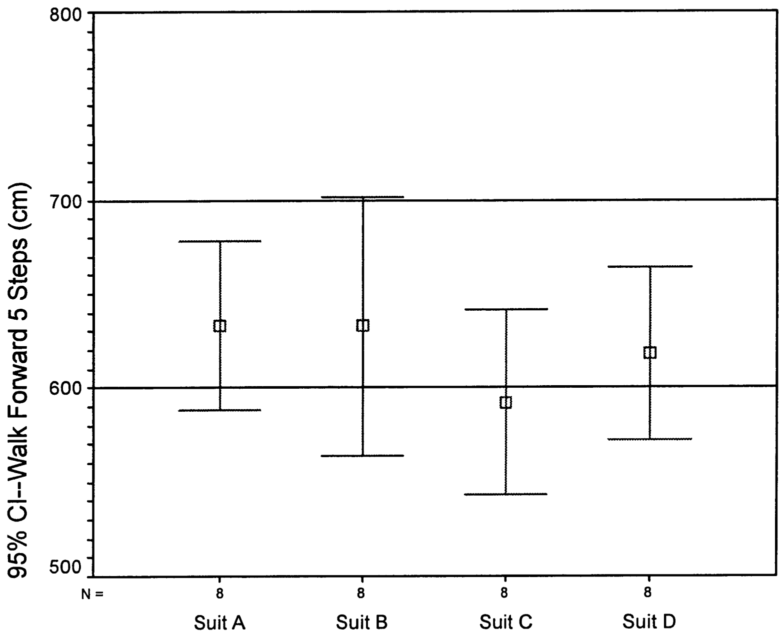
All of the subjects were able to complete the Kneel and Rise task without assistance from an experimenter or a chair (all were rated at '3').

Table 6 lists the means and standard deviations from the body mobility tasks by suit type. Figures 8-16 present error bar charts for each of the body mobility tasks tested statistically.

Table 6. Mean Body Mobility by Suit.

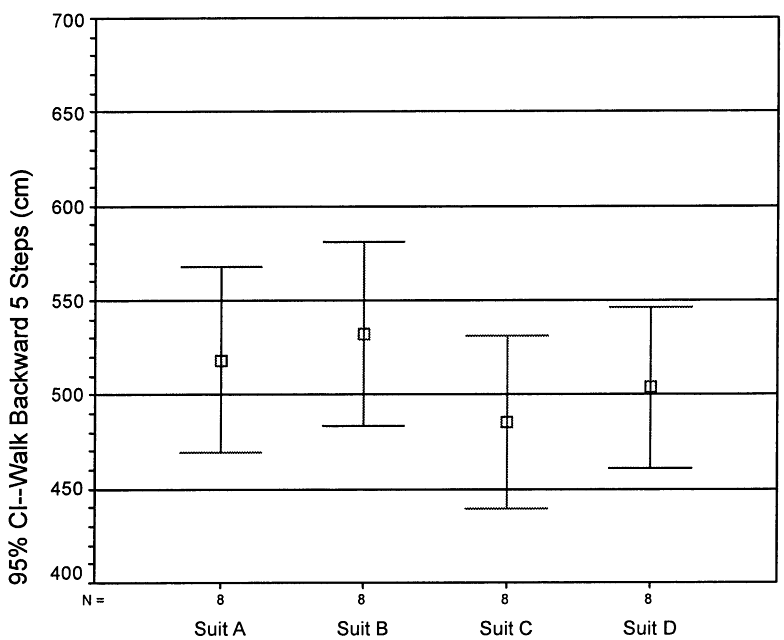
(degrees)		**Walk Forward 5 Steps**	**Walk Backward 5 Steps**	**Walk Sideways 5 Steps**	**Upper Arm Abduction**	**Upper Arm Forward Extension**	**Upper Arm Backward Extension**	**Upper Leg Forward Extension**	**Upper Leg Backward Extension**	**Upper Leg Flexion**
Suit A	**Mean**	633.0	518.3	532.8	99.5	105.9	38.5	50.0	37.1	57.1
	SD	*54.2*	*58.8*	*52.6*	*13.6*	*14.3*	*6.2*	*7.6*	*4.4*	*7.6*
Suit B	**Mean**	632.7	532.2	536.0	100.6	107.0	35.3	49.5	34.3	58.7
	SD	*82.0*	*58.0*	*46.2*	*10.8*	*17.6*	*8.0*	*9.3*	*4.6*	*10.3*
Suit C	**Mean**	592.2	485.1	504.7	82.5	80.8	34.5	45.7	35.0	57.9
	SD	*58.5*	*54.8*	*44.6*	*13.2*	*15.6*	*5.7*	*7.6*	*6.4*	*8.1*
Suit D	**Mean**	618.1	503.7	535.2	104.8	116.4	39.6	48.2	38.4	52.7
	SD	*55.3*	*50.6*	*46.8*	*8.4*	*13.7*	*5.2*	*6.7*	*6.4*	*5.6*

Shaded columns indicate significant differences in means. The same shading indicates that means in the same group/shade are not different from one another or non-shaded cells, but are significantly different from cells with different shading at p<.05.



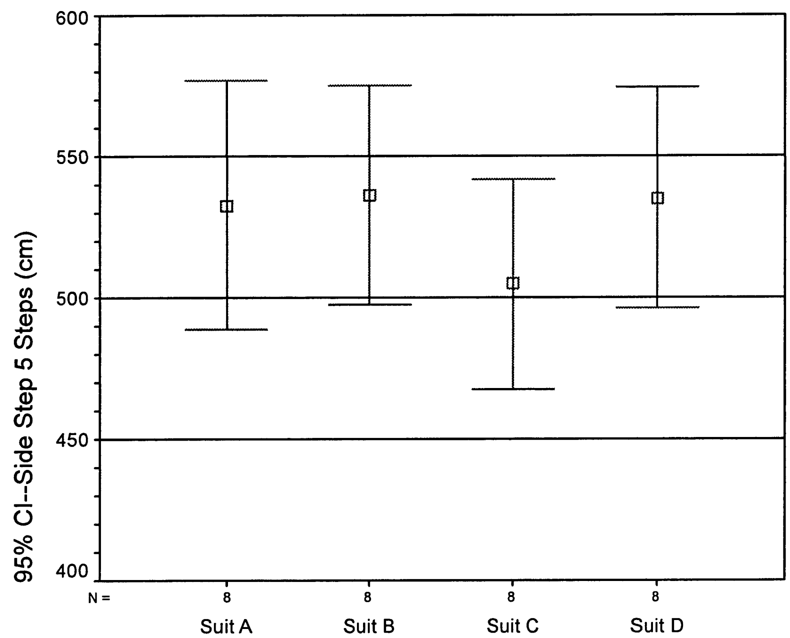
None of the suits' scores differed significantly (p<.05) on this task. N=number of subjects.

Figure 8. Error Bars for Walk Forward 5 Steps.



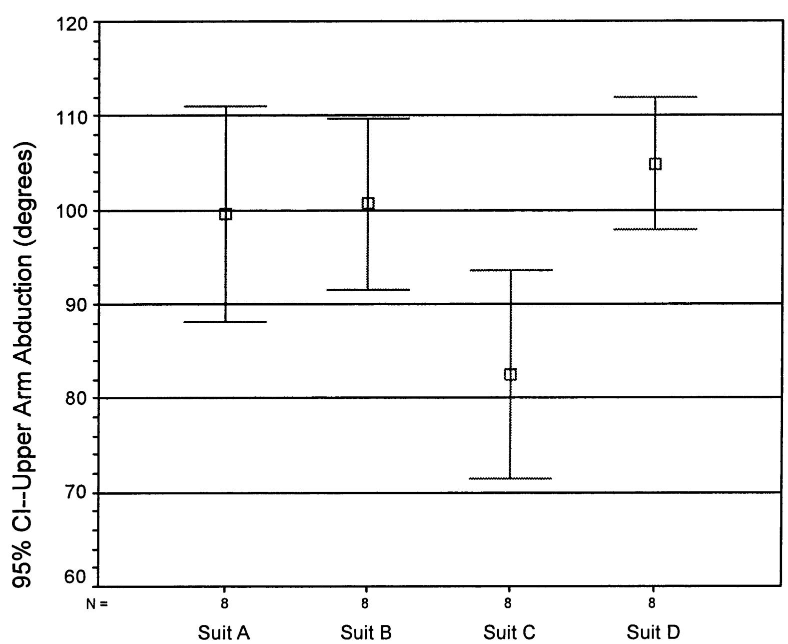
None of the suits' scores differed significantly (p<.05) on this task. N=number of subjects.

Figure 9. Error Bars for Walk Backward 5 Steps.



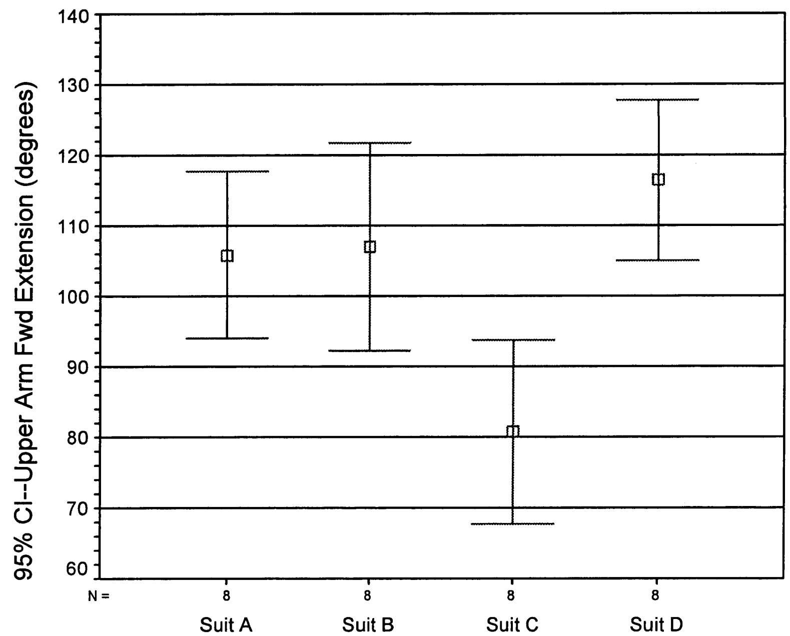
None of the suits' scores differed significantly (p<.05) on this task. N=number of subjects.

Figure 10. Error Bars for Side Step 5 Steps.



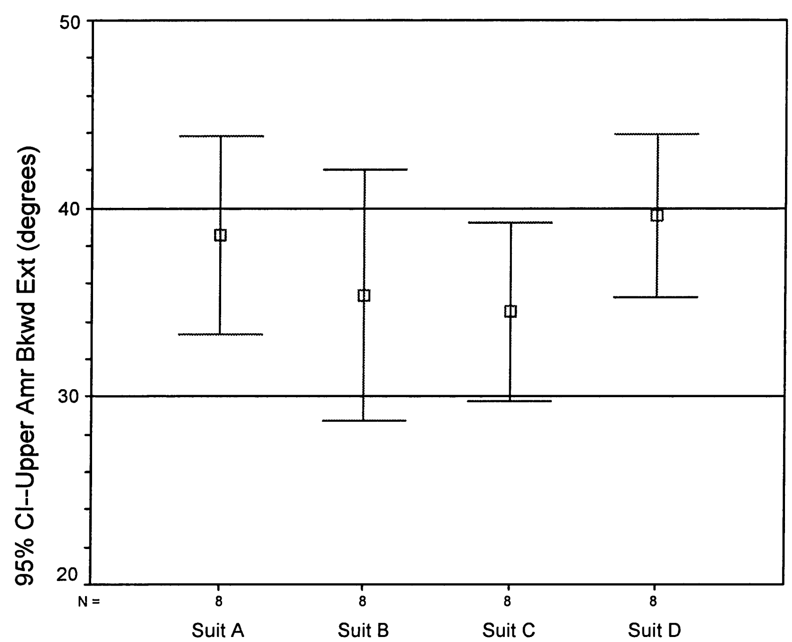
Note that Suit C had significantly less arm abduction than Suits B and D (but not A) (p<.05). N=number of subjects.

Figure 11. Error Bars for Upper Arm Abduction.



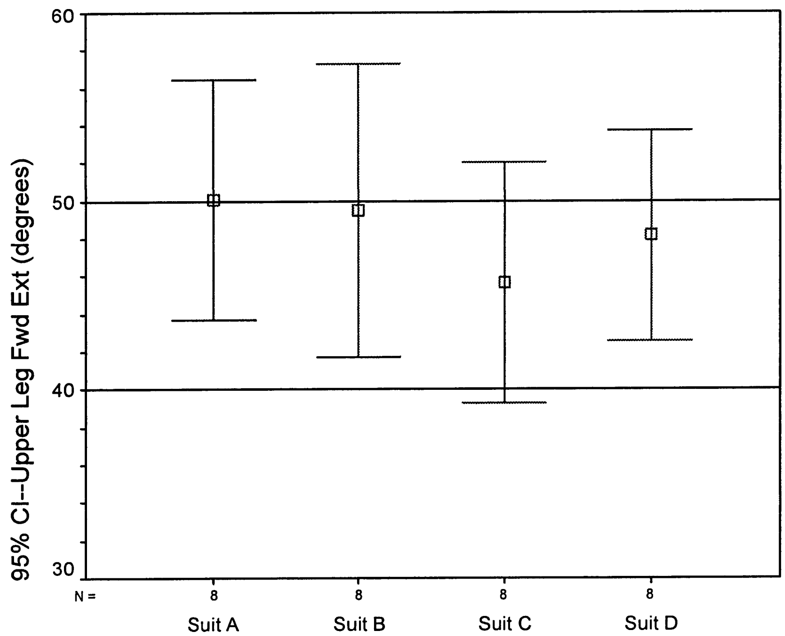
Note that Suit C had significantly less forward arm extension than the other 3 suits ($p<.05$). N=number of subjects.

Figure 12. Error Bars for Upper Arm Forward Extension.



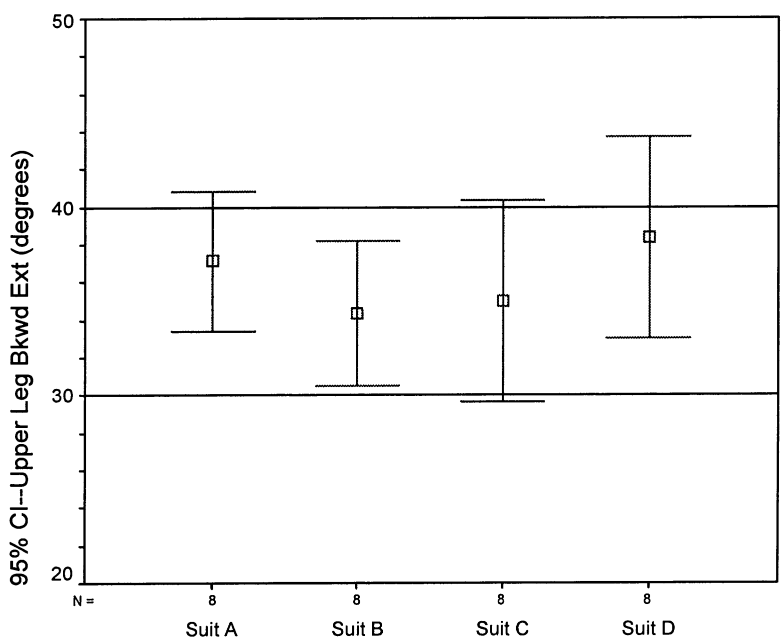
None of the suits' scores differed significantly ($p<.05$) on this task. N=number of subjects.

Figure 13. Error Bars for Upper Arm Backward Extension.



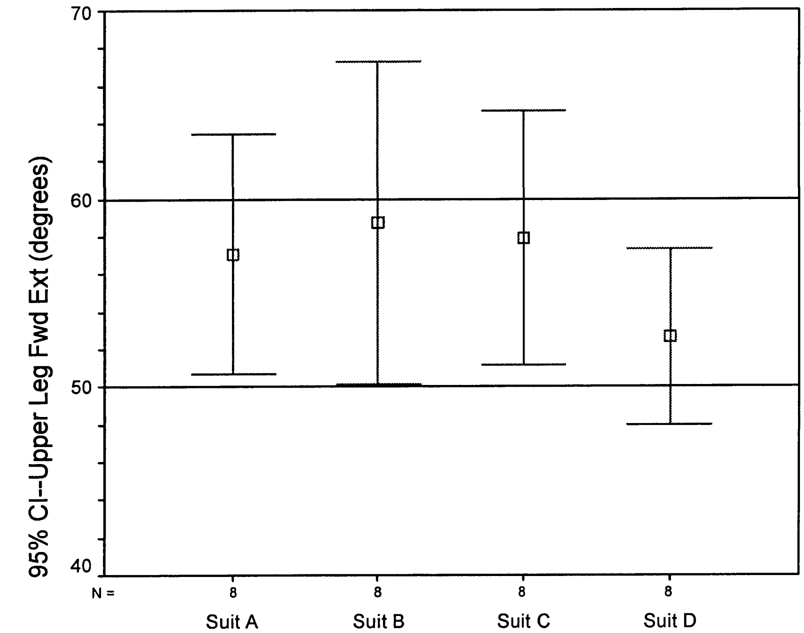
None of the suits' scores differed significantly (p<.05) on this task. N=number of subjects.

Figure 14. Error Bars for Upper Leg Forward Extension.



None of the suits' scores differed significantly (p<.05) on this task. N=number of subjects.

Figure 15. Error Bars for Upper Leg Backward Extension.



None of the suits' scores differed significantly (p<.05) on this task. N=number of subjects.

Figure 16. Error Bars for Upper Leg Flexion.

g. Test course 1 (negotiation to/from device). This course included walking and climbing over obstacles. The test criterion is time to complete the task.

On this task, completion time ranged from 2 minutes 12 seconds to 2 minutes 29 seconds. No significant differences between suits on completion time were found. Regardless of suit type or design, all of the subjects were able to complete the course.

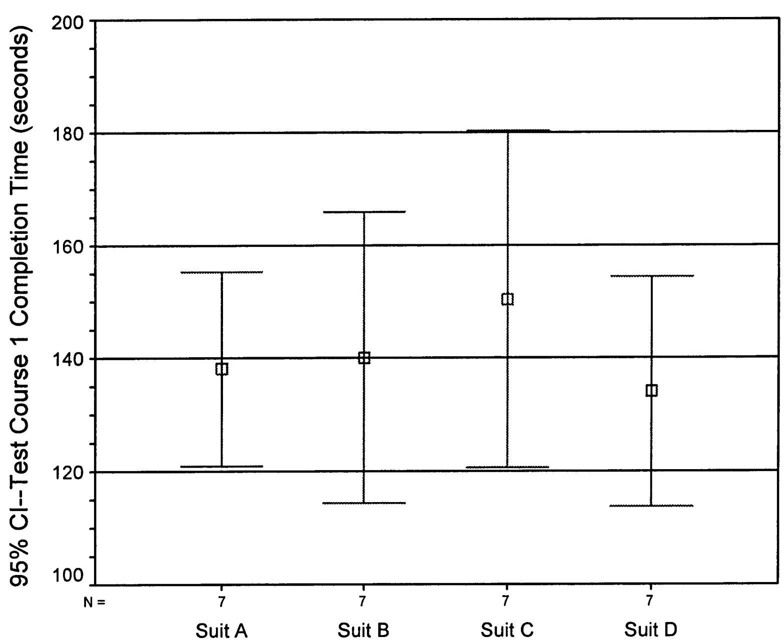
Observation of the subjects as they completed test course 1 yielded some interesting items. For example, some subjects walked very fast, while others walked rather slowly—speed appeared to be an individual difference rather than suit related. One subject used the handrail while descending and climbing the stairs. Some subjects reported that they could not see the stairs well and were negotiating them by "feel." One subject hit his helmet on the wall while he was climbing over the guardrail. Some subjects were able to easily climb over the guardrail, while others were tentative because of their lack of vision, the stiffness of the suit, or some combination of factors. Nonetheless, all subjects were able to complete all of the parts of this test course regardless of the suit they wore.

Table 7 reports test course 1's results by suit and Figure 17 shows error bars for the results.

Table 7. Mean Time to Complete Test Course 1.

Course 1 Time (min:sec)	Suit A	Suit B	Suit C	Suit D	Overall Course 1 Time
Mean	2:18	2:17	2:29	2:12	2:19
SD	*0:19*	*0:28*	*0:30*	*0:21*	*0:25*

There were no significant differences between suits for time to complete Test Course 1.



None of the suits' scores differed significantly (p<.05) on Test Course 1. N=number of subjects.

Figure 17. Error Bars for Test Course 1 Completion Time.

h. Test course 2 (disruption procedure). This course included processes conducted as the technician is 'on target,' in close proximity to the device. Two scores were generated for this test course. The time to complete the entire course was recorded as well as the "time on target," defined as the time while the test participant was within 10 feet (3.28m) of the test "device."

No significant differences between suits were found on either the entire course time or the "time on target." Times for the entire course ranged from 1 minute 57 seconds to 2 minutes 11 seconds. Times "on target" ranged from 1 minute 7 seconds to 1 minute 24 seconds. Times were proportional; in other words, the suit with the fastest time for the entire course was also the suit with the fastest "time on target" score. All of the subjects were able to complete the course successfully regardless of suit worn.

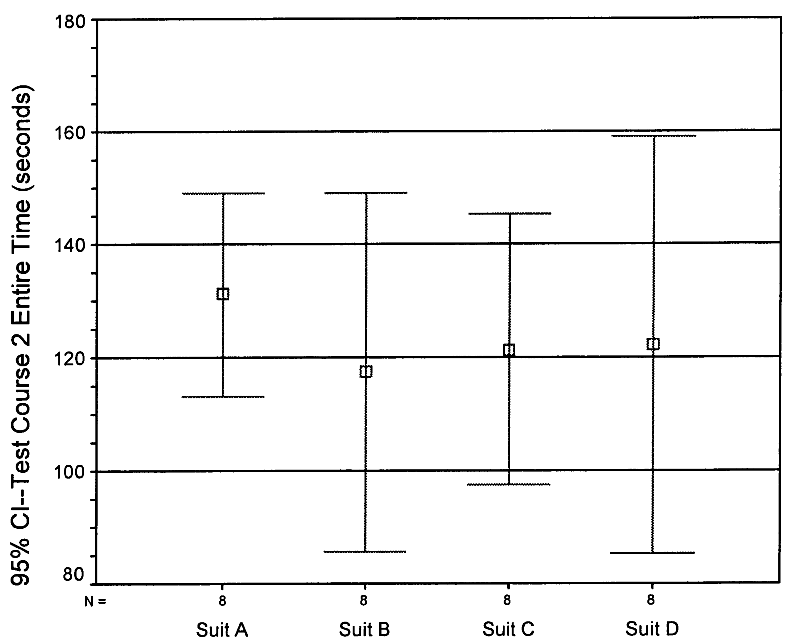
Most of the problems encountered in test course 2 appeared to be due to the subject's relative unfamiliarity with the bulk of the suit or the reduced visual field. There were instances of striking the disrupter against the door frame and against the table, striking one's helmet against the tabletop in setting up the disrupter, and difficulty in aligning the disrupter properly (usually because of the vision available through the face shield, not because the subject was unable to manipulate the disrupter).

Table 8 presents test course 2's results, and Figures 18 and 19 offer the error bars for the entire time and the time on target, respectively.

Table 8. Mean Times—Test Course 2.

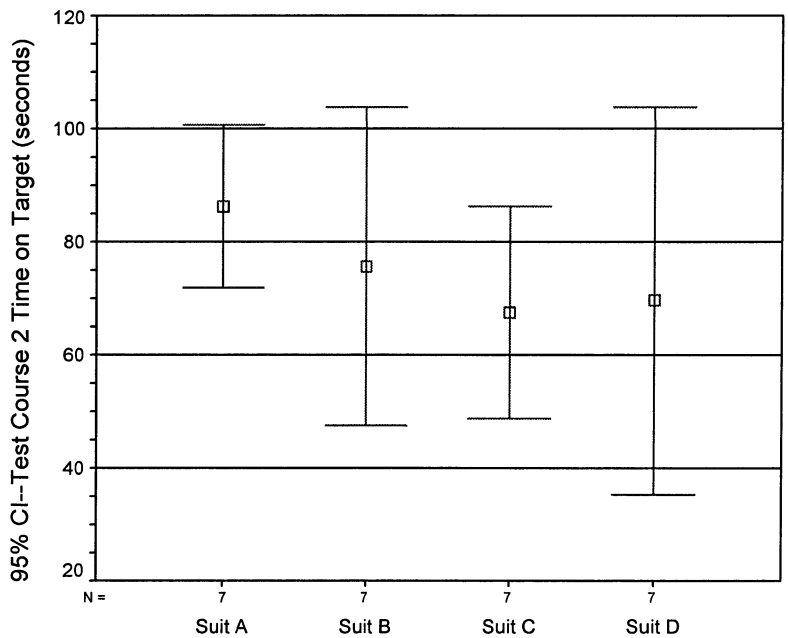
Test Course 2 Times (min:sec)	**Suit A**		**Suit B**		**Suit C**		**Suit D**		**Overall Course 2 Time**	
	Entire Course	On Target	Entire Course	On Target	Entire Course	On Target	Entire Course	On Target	Entire Course	On Target
Mean	2:11	1:24	1:57	1:14	2:01	1:07	2:02	1:08	2:03	1:14
SD	*0:21*	*0:16*	*0:38*	*0:28*	*0:29*	*0:20*	*0:44*	*0:35*	*0:33*	*0:26*

There were no significant differences between suits for time to complete the entire course or the time on target.



None of the suits' scores differed significantly (p<.05) on Test Course 2 Entire Completion Time. N=number of subjects

Figure 18. Error Bars for Test Course 2 Entire Completion Time.



None of the suits' scores differed significantly (p<.05) on Test Course 2 Time on Target. N=number of subjects.

Figure 19. Error Bars for Test Course 2 Time on Target.

i. Questionnaire. The questionnaire was based upon the questionnaire from a previous EOD suit study (reference a) and the EOD PPE user guide (reference b). For all of the questions, the rating scale was as follows:

1	2	3	4
Completely Unacceptable	**Barely Acceptable**	**Acceptable**	**Very Good**

A Friedman non-parametric test was run for each question; this statistical test determines whether significant differences exist between ratings awarded to each suit on a particular question. Ideally, each suit's mean rating on a particular question should be no lower than a rating of 3, indicating at least "Acceptable" performance on that particular attribute.

Of the 16 questions, 12 demonstrated significant differences between the suits for the ratings given by the test participants. In addition, the ratings show whether the test participants felt a particular attribute of a suit was acceptable to them. Tables 9 and 10 present the questionnaire results. Comments written in explanation to the questions are presented by suit in the Appendix.

(1) Question 1 (ability to don properly). This question had no differences between the four tested suits. Mean ratings ranged from 3.25 to 3.75, or between

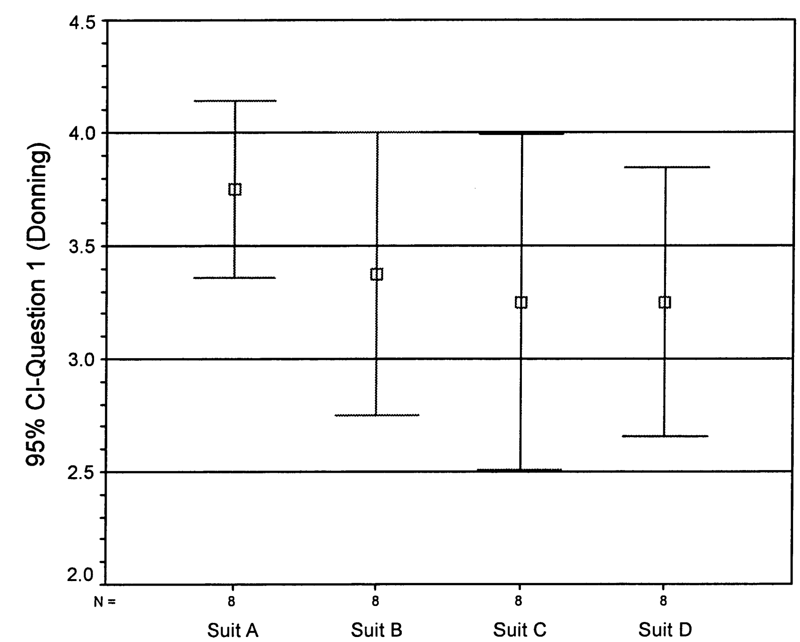
"Acceptable" and "Very Good." None of the subjects felt they had great difficulty in donning the suit. Figure 20 presents the error bars for Question 1.

Table 9. Results of Questions 1-8.

Suit Type	Statistic	Q1 Donning	Q2 Fit (suit)	Q3 Fit (Helmet)	Q4 Comfort (suit)	Q5 Comfort (Helmet)	Q6 Vision (FOV)	Q7 Vision (clarity)	Q8 Hearing
Suit A	**Mean**	3.75	3.38	2.50	3.13	2.38	2.25	3.75	3.88
	SD	*0.46*	*0.52*	*0.76*	*0.83*	*1.06*	*1.16*	*0.46*	*0.35*
Suit B	**Mean**	3.38	3.50	3.50	3.25	3.00	3.00	3.13	2.00
	SD	*0.74*	*0.53*	*0.53*	*0.71*	*0.58*	*0.93*	*0.83*	*1.07*
Suit C	**Mean**	3.25	2.88	1.88	2.25	2.13	2.25	1.75	2.50
	SD	*0.89*	*1.13*	*0.83*	*0.89*	*1.13*	*1.04*	*0.46*	*0.76*
Suit D	**Mean**	3.25	3.63	3.50	3.63	3.50	3.75	4.00	2.50
	SD	*0.71*	*0.52*	*0.76*	*0.52*	*0.76*	*0.46*	*0.00*	*1.07*

Note: Questions with titles in red had significant differences in ratings based on Friedman non-parametric test *($p<.05$)*
Scale: 1=Completely Unacceptable, 2=Barely Acceptable, 3=Acceptable, 4=Very Good

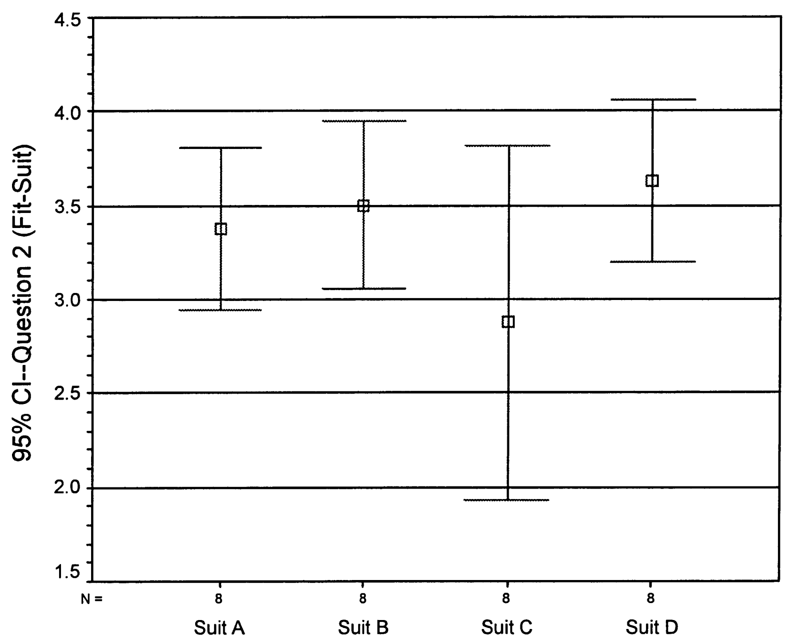
(2) Question 2 (suit fit). Recall that the subjects were fitted for the suits prior to the start of the evaluation and all of them were fitted into the proper size of suit available. Ratings on this question differed significantly from one another. Ratings ranged from 2.88 for Suit C to 3.63 for suit D. Suits A and B were rated at 3.38 and 3.5, respectively. Suit C was the only suit rated below "Acceptable" for fit. Figure 21 presents the error bars for Question 2.



None of the suits' scores differed significantly ($p<.05$) on Question 1. N=number of subjects.

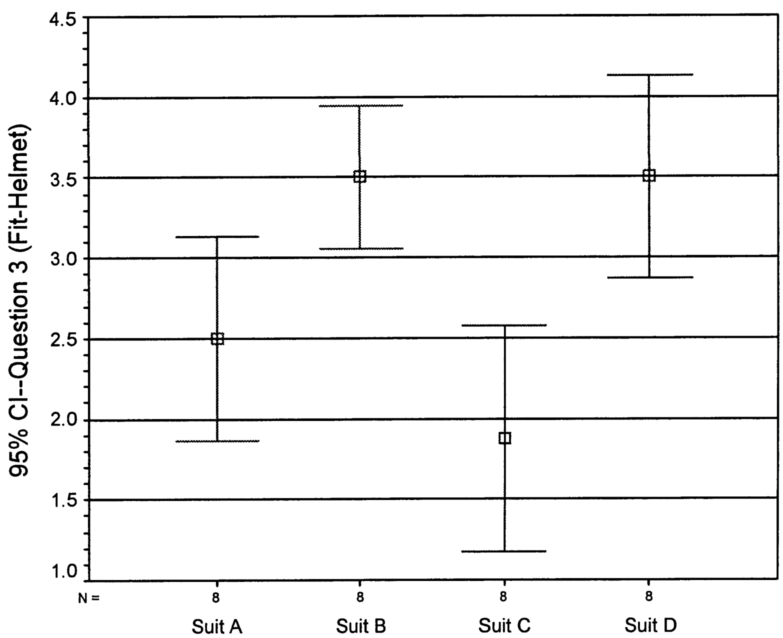
Figure 20. Error Bars for Question 1.

(3) Question 3 (helmet fit). Ratings on this question differed significantly from one another. Ratings fell between "Completely Unacceptable" and "Barely Acceptable" (1.88) for Suit C's helmet; between "Barely Acceptable" and "Acceptable" (2.5) for Suit A's helmet, and between "Acceptable" and "Very Good" (3.5) for both Suit B's and Suit D's helmets. Despite adjustment and fitting of the helmets to the head prior to the start of the evaluation, the helmets did not always stay in place on the head. Some of the problems for Suits A and C were due to the chinstrap design and fastening method. Figure 22 presents the error bars for Question 3.



The suits' scores differed significantly (p<.05) on Question 2. N=number of subjects.

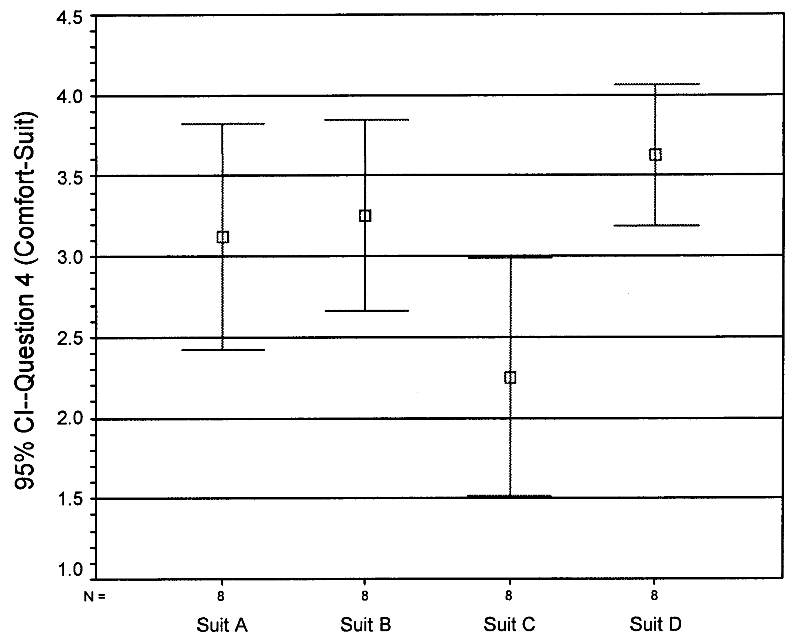
Figure 21. Error Bars for Question 2.



The suits' scores differed significantly (p<.05) on Question 3. N=number of subjects.

Figure 22. Error Bars for Question 3.

(4) Question 4 (suit comfort). Ratings on this question differed significantly from one another. Suit C had the lowest rating (2.25), between "Barely Acceptable" and "Acceptable," while the other three suits were rated "Acceptable" or better for suit comfort (Suit A=3.13, Suit B=3.25, Suit D=3.63). Suit C's low comfort rating is consistent with its low rating for suit fit on question 2. Figure 23 presents the error bars for Question 4.

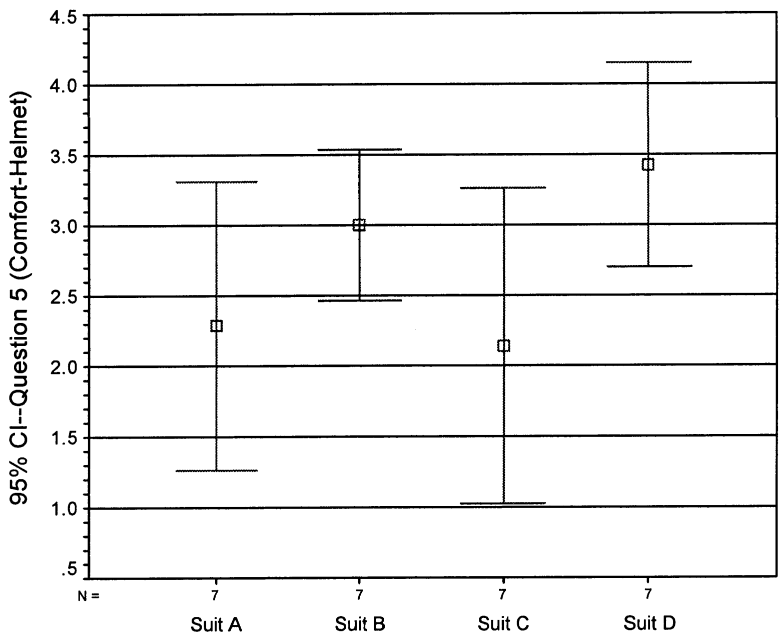


The suits' scores differed significantly (p<.05) on Question 4. N=number of subjects.

Figure 23. Error Bars for Question 4.

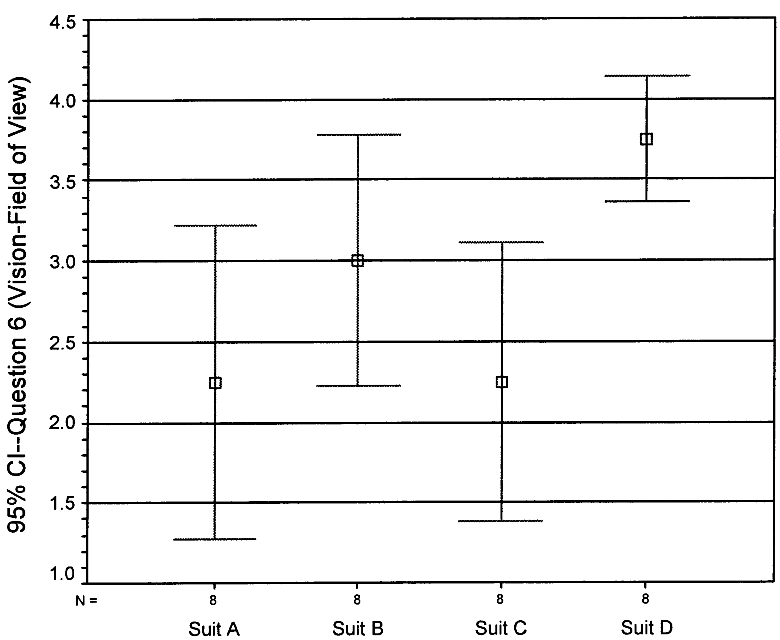
(5) Question 5 (helmet comfort). Subjects' ratings on helmet comfort differed significantly from one another. Suit C had the lowest rating (2.13), between "Barely Acceptable" and "Acceptable." Suit A's rating (2.38) also fell in that range. Ratings for Suits B and D were both "acceptable" or better (3.0 and 3.5, respectively). Figure 24 presents the error bars for Question 5.

(6) Question 6 (vision-field of view). The subjects' mean ratings differed significantly from one another for field of view acceptability. Suits A and C had the lowest ratings (2.25), between "Barely Acceptable" and "Acceptable." Suit B's rating of 3.0 was "Acceptable," and Suit D's 3.75 rating was between "Acceptable" and "Very Good." It appears that the subjects' ratings correspond to their perception of field of view in the downward direction—Suits A and C had the least downward field of view, and Suits B and D had the greatest. Figure 25 presents the error bars for Question 6.



The suits' scores differed significantly (p<.05) on Question 5. N=number of subjects.

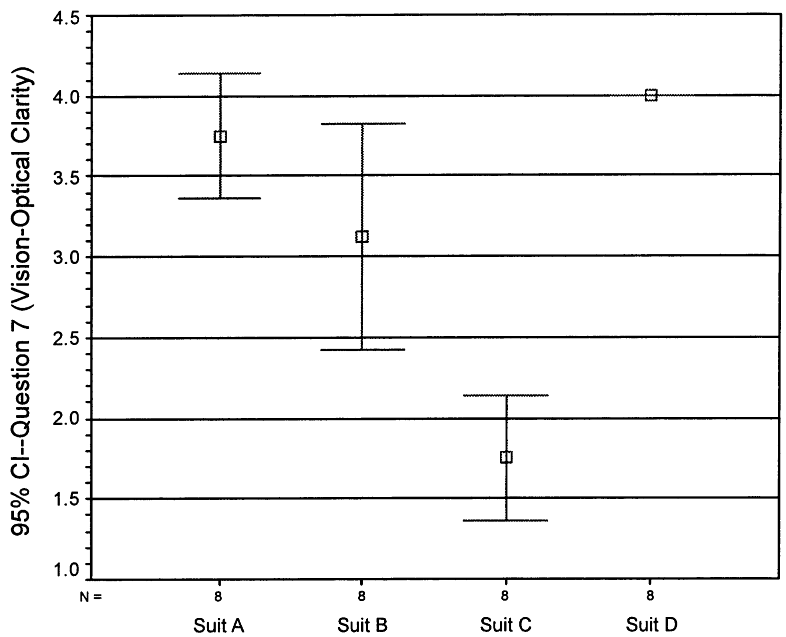
Figure 24. Error Bars for Question 5.



The suits' scores differed significantly (p<.05) on Question 6. N=number of subjects.

Figure 25. Error Bars for Question 6.

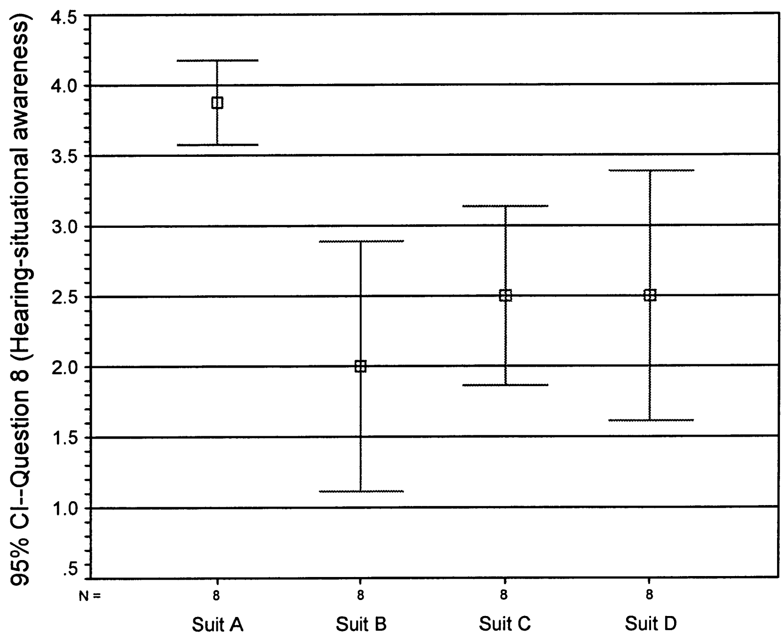
(7) Question 7 (vision-clarity). The mean ratings for the suits differed significantly from one another for visual clarity. Suit C had the lowest rating (1.75), between "Completely Unacceptable" and "Barely Acceptable." The other three suits were rated between 3.1 and 4.0, or between "Acceptable" and "Very Good." Suit D had the best rating for this attribute, at 4.0. Suit A had a mean rating of 3.75, and Suit B was rated at 3.13. Note that no defects (cracks, scratches, etc.) were found in any of the face shields before, during, or after testing. When face shields were cleaned, a liquid was always used to reduce the chance of scratching the face shield (though most had some type of anti-scratch coating). Some component of this rating is related to the amount of fogging experienced by the test subjects, since suit C tended to have the most instances of fogging during the evaluation. Figure 26 presents the error bars for Question 7.



The suits' scores differed significantly ($p<.05$) on Question 7. N=number of subjects.

Figure 26. Error Bars for Question 7.

(8) Question 8 (hearing—situational awareness). The suits differed significantly from one another for their ability to allow subjects to hear voices and ambient sound. Suit B had the lowest rating (2.0), or "Barely Acceptable." Suits C and D had mean ratings of 2.5, or between "Barely Acceptable" and "Acceptable." Suit A's mean rating was the highest, at 3.88, or just under "Very Good." Suits with hearing amplification systems were tested with those systems powered and operating, although it is suspected that one was malfunctioning. The appendix has details. Figure 27 presents the error bars for Question 8.



The suits' scores differed significantly (p<.05) on Question 8. N=number of subjects.

Figure 27. Error Bars for Question 8.

Table 10. Results of Questions 9-16.

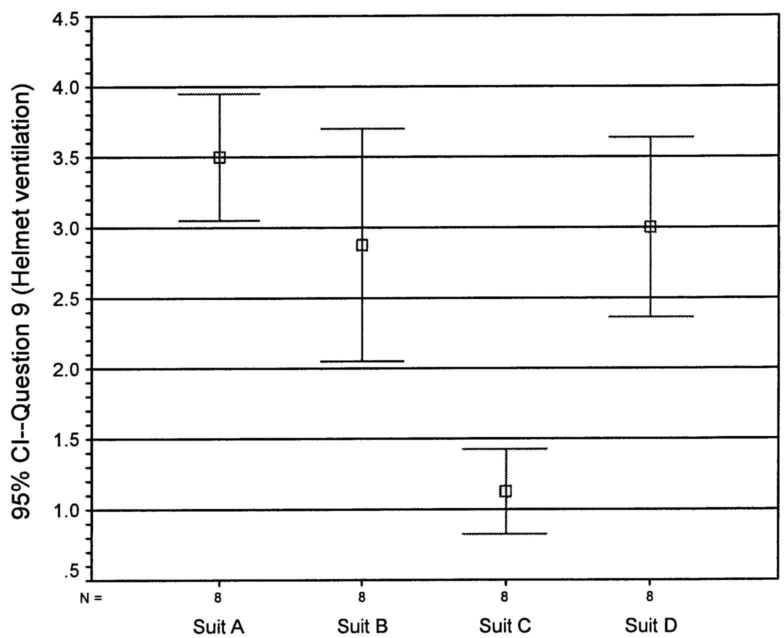
Suit Type	Statistic	Q9 Helmet Ventil-ation	Q10 Walking	Q11 Stability	Q12 Flexibility	Q13 Weight/ Balance	Q14 Task Perform-ance	Q15 Cooling System Adequacy	Q16 Doffing
Suit A	**Mean**	3.50	3.63	3.50	2.88	3.13	2.88	3.00	3.88
	SD	*0.53*	*0.52*	*0.76*	*0.64*	*0.83*	*0.99*	*1.07*	*0.35*
Suit B	**Mean**	2.88	3.25	3.50	3.13	3.13	3.25	3.00	3.88
	SD	*0.99*	*0.89*	*0.76*	*1.13*	*0.64*	*0.71*	*1.00*	*0.35*
Suit C	**Mean**	1.13	3.25	2.50	2.25	3.13	2.75	1.29	3.88
	SD	*0.35*	*0.71*	*1.07*	*0.89*	*0.83*	*0.89*	*0.49*	*0.35*
Suit D	**Mean**	3.00	3.75	3.88	3.13	3.50	3.75	3.25	3.43
	SD	*0.76*	*0.46*	*0.35*	*0.83*	*0.53*	*0.46*	*1.04*	*0.53*

Note: Questions with titles in red had significant differences in ratings based on Friedman non-parametric test *(p<.05)*
Scale: 1=Completely Unacceptable, 2=Barely Acceptable, 3=Acceptable, 4=Very Good

(9) Question 9 (helmet ventilation). All of the suits' ventilation systems were operating during the test, and subjects were allowed to vary the ventilation volume (if the feature existed) at any time for as long as they wished. System batteries were changed before each test session so that each test participant had fresh batteries for their session. Therefore, ratings for helmet ventilation reflect a fully operable ventilation system with full design voltage and current available.

The mean ratings for the suits differed significantly from one another for helmet ventilation. Suit C had the lowest rating (1.13), just above "Completely

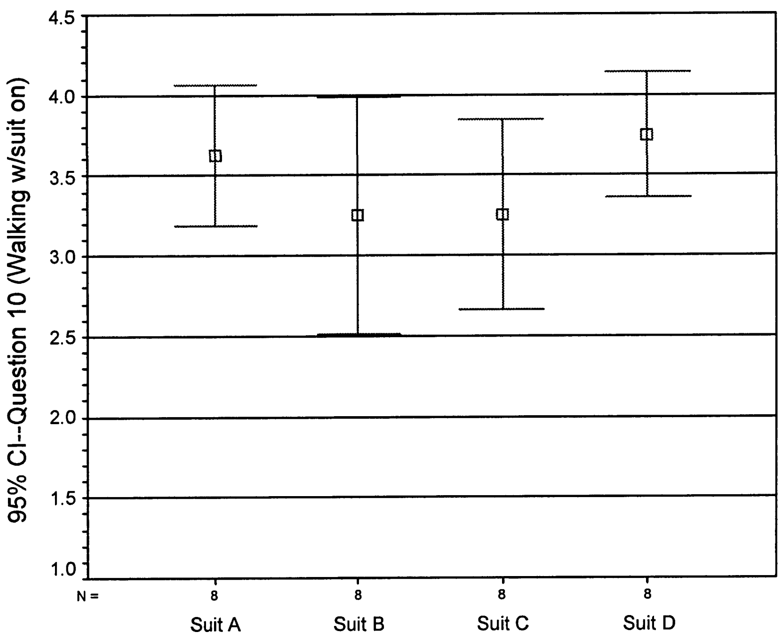
Unacceptable." This rating is consistent with the comments of the test participants throughout the test that they were unable to feel much if any ventilation or airflow within suit C's helmet. The other three suits were rated between 2.8 and 3.5, or between "Barely Acceptable" and "Very Good." Suit B was rated at 2.88, Suit D was rated at 3.0, and Suit A was rated at 3.5 for helmet ventilation. Figure 28 presents the error bars for Question 9.



The suits' scores differed significantly ($p<.05$) on Question 9. N=number of subjects.

Figure 28. Error Bars for Question 9.

(10) Question 10 (walking). There were no significant differences between suits for the rating of the ability to walk while in the suit. The ratings all fell between "Acceptable" and "Very Good." Suit A was rated at 3.63, Suits B and C were rated at 3.25, and Suit D was rated at 3.75. The ratings are consistent with comments and observations recorded during the evaluation, as well as with the scores for the test courses. Subjects generally did not have difficulty in walking in any of the suits. Figure 29 presents the error bars for Question 10.

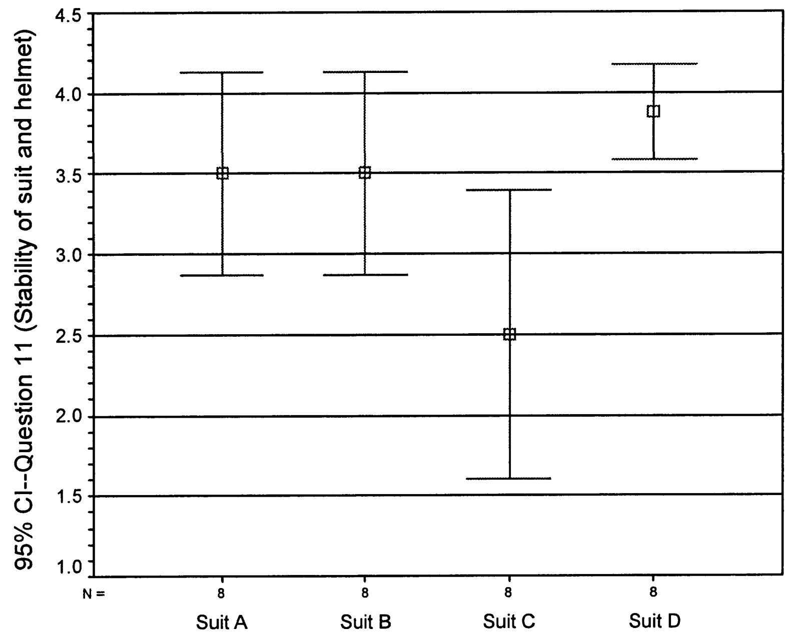


The suits' scores did not differ significantly (p<.05) on Question 10. N=number of subjects.

Figure 29. Error Bars for Question 10.

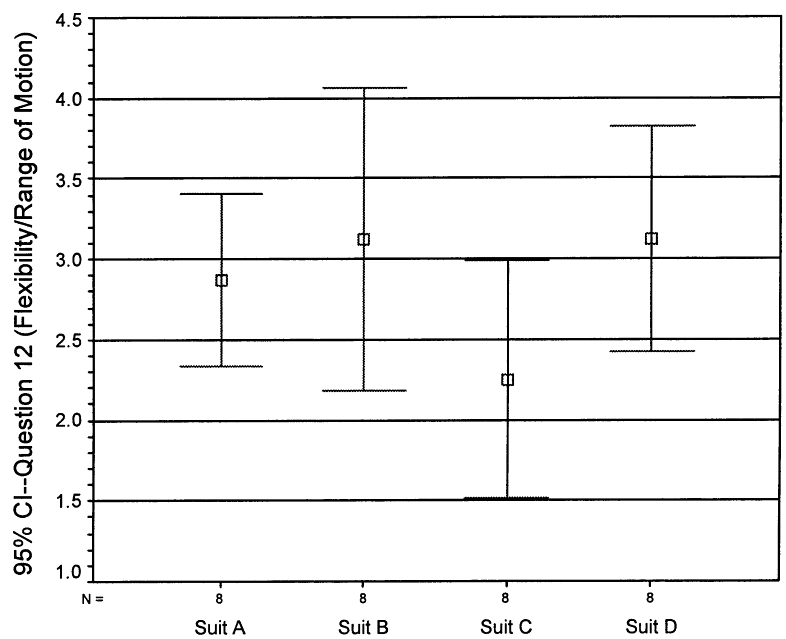
(11) Question 11 (stability of suit and helmet). The mean ratings for the suits for suit and helmet stability differed significantly from one another. Suit C had the lowest rating (2.5), falling between "Barely Acceptable" and "Acceptable," while the other suits had ratings between "Acceptable" and "Very Good," at 3.5 to 3.88. One influence on the stability rating may be the helmet's fit, especially for suit C, which had the lowest rating (below "Barely Acceptable") for helmet fit. Figure 30 presents the error bars for Question 11.

(12) Question 12 (flexibility/range of motion). Flexibility/range of motion mean ratings for the suits differed significantly from one another. Suit C had the lowest rating (2.25), falling between "Barely Acceptable" and "Acceptable," suit A was rated at 2.88, also between "Barely Acceptable" and "Acceptable," and suits B and D both had mean ratings of 3.13, or between "Acceptable" and "Very Good." These ratings correspond with scores on the body mobility tasks and scores of the Test Courses and the Minnesota Test, where time to complete the task was affected by the flexibility and range of motion of the suits. The suits with higher ratings on Question 12 were those that scored better on these tasks. Figure 31 presents the error bars for Question 12.



The suits' scores differed significantly (p<.05) on Question 11. N=number of subjects.

Figure 30. Error Bars for Question 11.

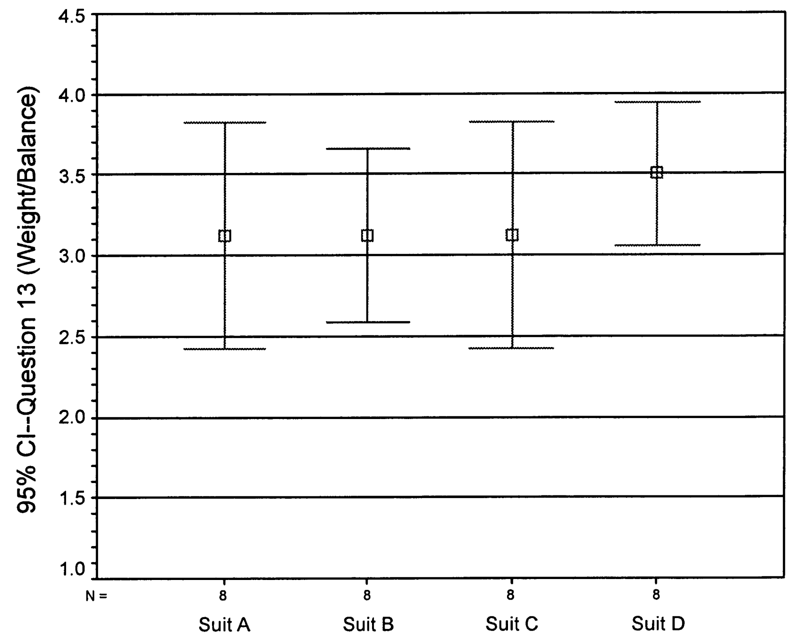


The suits' scores differed significantly (p<.05) on Question 12. N=number of subjects.

Figure 31. Error Bars for Question 12.

(13) Question 13 (weight/balance). The mean scores for suit weight and balance were not significantly different from one another. Subjects awarded suits A, B, and C the same mean rating of 3.13, and suit D received a mean rating of 3.5. These

means fall between "Acceptable" and "Very Good." Observational data were consistent with these ratings that the suits were well balanced on the body. Subjects tended to comment on the weight of the suit mostly after noticing the reduction in weight once the suit was removed, but they did not often comment on the weight of the suit in particular during the evaluation. Figure 32 presents the error bars for Question 13.



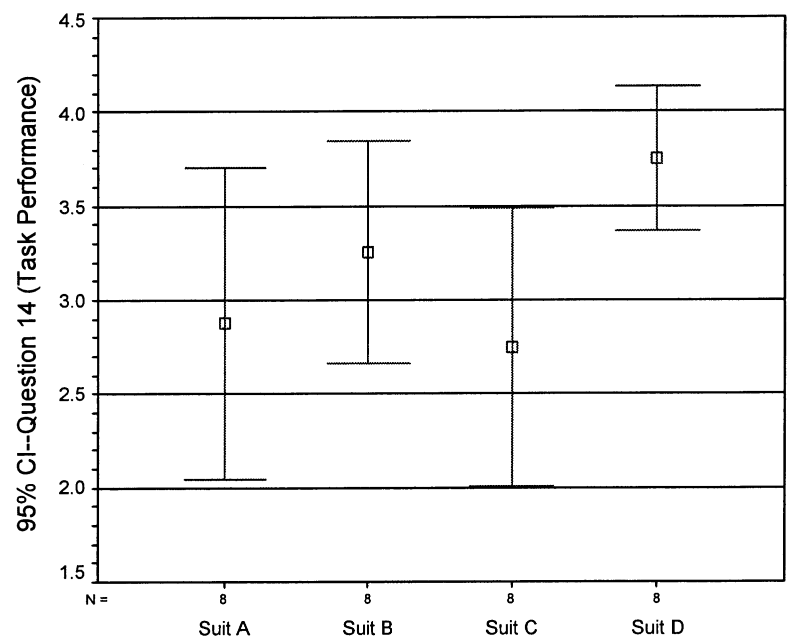
The suits' scores did not differ significantly (p<.05) on Question 13. N=number of subjects.

Figure 32. Error Bars for Question 13.

(14) Question 14 (Task Performance). Task performance ratings were not significantly different across the suits. Two of the suits were rated below 3.0 or "Acceptable" (Suit A at 2.88 and Suit C at 2.75) and two (Suit B at 3.25 and Suit D at 3.75) were rated between 3.0 ("Acceptable") and 4.0 ("Very Good"). Comments from the subjects indicated that they generally felt that task performance was not compromised greatly by the suits, and their ratings reflect this belief. Figure 33 presents the error bars for Question 14.

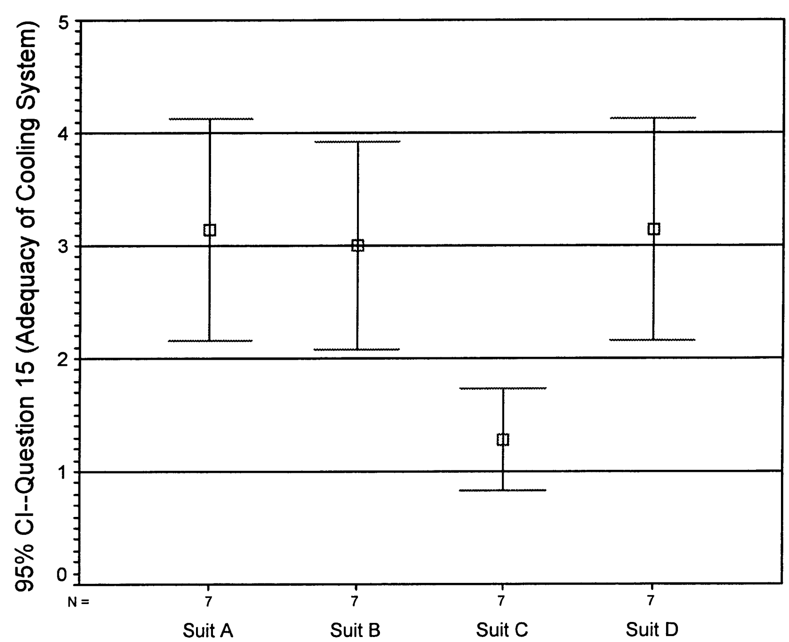
(15) Question 15 (adequacy of cooling system). Mean ratings for adequacy of the suit cooling system differed significantly across suits. Note that none of the systems was operated with a traditional liquid based cooling system, but one system did include a ventilation system for the back torso. Subjects thus likely answered the question based on the presence and performance of the helmet ventilation and thoracic ventilation systems. Subjects rated suits A, B and D between "Acceptable" and "Very Good" (3.0, 3.0 and 3.25, respectively), while Suit C's mean rating was 1.29, or between "Completely Unacceptable" and "Barely Acceptable." These ratings are consistent with comments and observations during the evaluation, as well as with other questions' ratings (such as question 9, Helmet Ventilation, where suit C received a rating of 1.13 while suits A, B and D were rated near or above 3.0).

Suit cooling systems, if they existed, were fully functional during the evaluation. No failures occurred that would have had an effect upon the ratings for Question 15. Figure 34 presents the error bars for Question 15.



The suits' scores did not differ significantly (p<.05) on Question 13. N=number of subjects.

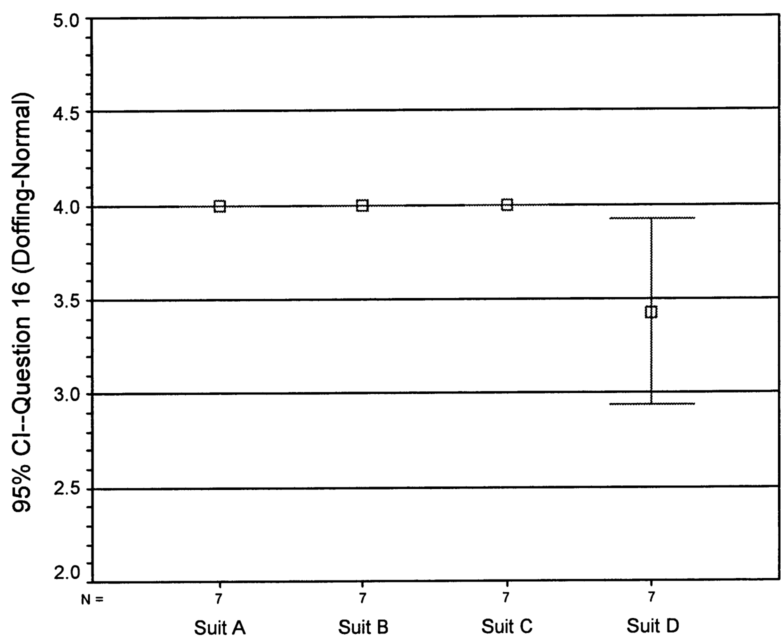
Figure 33. Error Bars for Question 14.



The suits' scores differed significantly (p<.05) on Question 15. N=number of subjects.

Figure 34. Error Bars for Question 15.

(16) Question 16 (ability to doff properly). Although all of the mean ratings fell between "Acceptable" and "Very Good," the ratings were significantly different for doffing. Suit C had a mean rating of 3.43, and the other three suits (A, B, and D) had mean ratings of 3.88. None of the subjects felt they had great difficulty in doffing the suit, and the evaluators did not have difficulty in assisting the subjects with doffing. Figure 35 presents the error bars for Question 16.



The suits' scores differed significantly (p<.05) on Question 16. N=number of subjects.

Figure 35. Error Bars for Question 16.

j. Final Rankings. At the conclusion of the evaluation, subjects were asked to rank-order the four suits, in order of preference from first through fourth, based on their experiences with all of the suits. They also explained why they ranked the suits in a particular order. Table 11 displays the rankings and number of "votes" by suit.

From the rankings, suits A and D appear to have been the most preferred suits, tied with the greatest number of first-place ranks (3), with Suit B close behind (2). However, suits A, B, and D were ranked very closely. The three were ranked first or second for 5 of the 8 test participants, with no fourth-place ranking for suits A and D and only one for suit B. It is also clear that suit C was not preferred by the test participants, since 7 of the 8 ranked suit C last. Clear reasons were offered as explanations for the rankings awarded. Explanations of the ranks are provided in the Appendix by suit.

Table 11. Subjective Suit Rankings (order of preference).

Rank (n)	Suit A	Suit B	Suit C	Suit D
First	3	2	0	3
Second	2	3	1	2
Third	3	2	0	3
Fourth	0	1	7	0

k. Additional Tests. In conjunction with the human factors tasks detailed above, the tested suits were evaluated on several additional items. Results from these tests are mainly suit-specific; most of the results are therefore presented in the appendix. The battery test items are reported on in the aggregate and are presented below.

(1) Battery Life. Battery life was observed only in terms of the ability of a suit's power supply to operate for the duration of a test session with one subject. A fresh set of batteries (either new alkaline cells or fully recharged pack, as appropriate) was installed in each suit prior to the start of a test session. Blowers and defoggers (when present) were always switched "on" for the duration of each test session. Subjects were free to adjust blower speed (if the suit allowed such adjustment) as they saw fit, and all did so. This did not have a detrimental effect upon battery life. All of the power supplies remained functional throughout the duration of each entire test session, which ran between 90 and 120 minutes.

(2) Ability to remove and/or change batteries without tools. None of the suits required more than a coin or small screwdriver to turn screw clips in order to remove the cover from a battery compartment or holder. Battery changes in all cases were quick and easily accomplished. More specific battery change information is found in the Appendix.

This document reports research undertaken at the U.S. Army Research, Development and Engineering Command, Natick Soldier Center, Natick, MA, and has been assigned No. NATICK/TR-06/014 in a series of reports approved for publication.

References

a. Johnson , R.F. (1981). Effects of explosive ordnance disposal (EOD) armor on the gross body mobility, psychomotor performance, speech intelligibility, and visual field of men and women. (Technical Report NATICK/TR-81/031). US Army Natick Research and Development Command, Natick, MA.

b. Draft Explosive Ordnance Disposal Personal Protective Equipment (EOD PPE) User Guide, February 2005.

c. Test Plan for Benchmarking Ergonomics Evaluation of Explosive Ordnance Disposal (EOD) Suits for EOD PPE Standard Program